Question 1

(a) • Carbonation:

$$x = k \cdot \sqrt{t}$$

with $x = 30\,mm$ $\Rightarrow$ $\underline{k = 4{,}93\,mm/y^2}$

$t = 37y$

• Chloride ingress:

$$c = c_0 \cdot \{1 - \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

using: $z = \frac{x}{2\sqrt{Dt}}$

$x = 30$

$c_0 = 1{,}60\%$ and $c = 0{,}3\%$

$t = 37y \cdot 365 \cdot 24 \cdot 3600 = 1{,}17 \cdot 10^9\,s$

$\rightarrow \mathrm{erf}(z) = 0{,}813$

using table on datasheet: $z = 0{,}931$

so $D = \underline{2{,}22 \cdot 10^{-13}}\,m^2/s$ ($7{,}012\,mm^2/y$) [3p]

(b)(i). Determine critical cover depth:

cover normally distribute with mean of 39mm

and SD = 4 mm.

10% fractile: $39 - 1{,}282 \cdot 4 = 33{,}9\,mm$

↑ using table on datasheet.

• Carbonation after 52y

$$x = 4{,}93 \cdot \sqrt{52} = 35{,}6\,mm > \underline{33{,}9\,mm}\,!$$

• Chloride content at critical cover depth after 52y:

$t = 52 \cdot 365 \cdot 24 \cdot 3600 = 1{,}64 \cdot 10^9\,s$

$c_0 = 1{,}60\%$ $\quad D = 2{,}22 \cdot 10^{-13}\,m^2/s$

$x = 33{,}9\,mm$

$$c = 1{,}60 \cdot \left(1 - \mathrm{erf}\left(\frac{33{,}9}{2\sqrt{2{,}22 \cdot 10^{-13} \cdot 1{,}64 \cdot 10^{3}}}\right)\right)$$

4p

$= 0{,}34\,\%$

(ii) • Carbonation depth from (b)(i) = 35,6 mm > 33,9 mm ← critical depth.

• chlorides : from (b)(i) chlorides at critical depth is 0,34 % < 0,4 % critical content.

⇒ intervention required for carbonation induced corrosion

• 3 measures:

* concrete protection:
  - cathodic protection of steel
  - coating of concrete limiting CO_2 permeability
  - keep concrete dry → prevents corrosion

* concrete repair :
  - remove carbonated concrete and repair with repair mortar
  - cast extra cover layer around elements.

...

2p

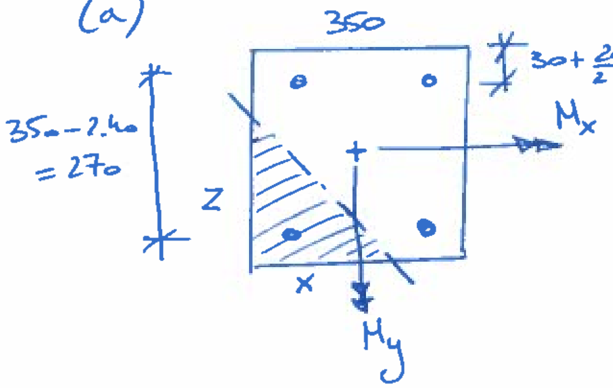
(c) Examples are:

- cracking due to : • shrinkage
  • creep
  • deformations / overloading
- Alkali Silica reaction
- Sulphate attack
- Freeze-thaw with(out) de-icing salts
- Biogenic sulfuric acid corrosion (unlikely for car park)

1p

Question 2

(a)



$f_{cd} = 30\,MPa \rightarrow 0.6 f_{cd} = 18\,MPa$

$f_{yd} = 435\,MPa$

- Assume 1 bar in compression zone.
- Yield force of one bar:

$$A \cdot f_{yd} = \frac{20^2 \cdot \pi}{4} \cdot 435 = 136{,}66\,kN$$

- Force on concrete compression block:

$$F_c = N + 2 \cdot 136{,}66\,kN$$
$$= 200 + 273{,}3\,kN$$
$$= 473{,}3\,kN \qquad (1)$$

and $F_c = 0{,}6 f_{cd} \cdot \frac{x \cdot Z}{2} \qquad (2)$

Hence (1) = (2) $x = \frac{52591}{z} \qquad (3)$

- Moments about axes through the centre:

$$M_x = 136659 * 270 + 473318 \cdot \left(175 - \frac{z}{3}\right) \qquad (4)$$

$$M_y = 136659 * 270 + 473318 \left(175 - \frac{x}{3}\right) \qquad (5)$$

and: $M_y = 0{,}85 \cdot M_x \qquad (6)$

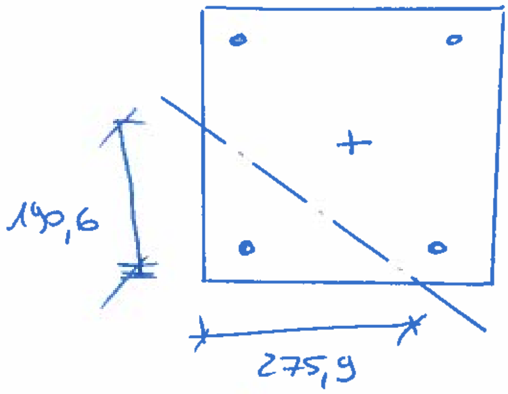
combining (3), (4), (5), (6) gives a quadratic in z:

$$z^2 + 133{,}92\, z - 61871{,}7 = 0$$

$$\Rightarrow z = 190{,}6\,mm \qquad (7)$$

and with (3) : $x = 275{,}9\,mm. \qquad (8)$

checking by drawing confirms initial assumption of 1 bar in compression zone is correct.



6,5p

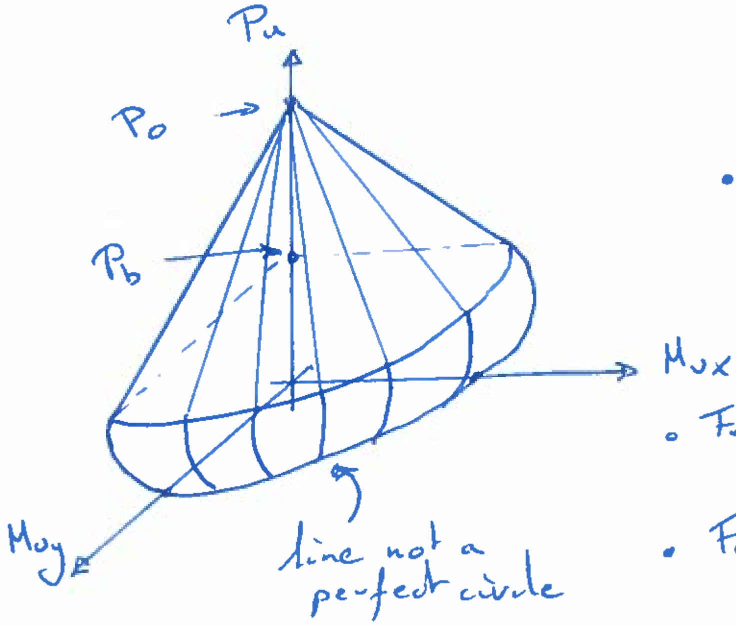
(b) Substitution of (7) and (8) in (4) and (5) gives:

$M_x = 89{,}65$ kNm
$M_y = 76{,}20$ kNm

} ratio indeed 0,85.

1p

(c)



- When $P_u = P_o$ full capacity of column is taken; no bending moment capacity left.
- For $P_u > P_b$: compression failure.
- For $P_u = P_b$: balanced failure: maximum bending moment capacity of column due to positive effect of axial load.
- For $P_u < P_b$: bending moment capacity reduced as full potential of axial load not developed leading to tension failure

Any combination of P, Mx and My within failure envelope can be taken by column.

2,5p

Question 3

(a) Total extension of cable under prestress:

$$\Delta \ell = \frac{\sigma_p}{E_s} \cdot L = \frac{1000}{200\,000} \cdot 30\,000 = 150 \text{ mm.}$$

wedge pull-in is 3mm so: $\frac{3}{150} = 0{,}02$ release

or $1000 \cdot 0{,}02 = 20\text{ MPa}$ prestress loss. [2,5p]

(b) . Effect of prestressing tendon 2 on tendon 1 which is already stressed:

$$\delta\sigma_1 = \frac{E_s}{E_c} \cdot P_2 \left(\frac{1}{A} + \frac{e_{y2}\, e_{y1}}{I_x} + \frac{e_{x2}\, e_{x1}}{I_y} \right) \quad (1)$$

with $A = 1500 \cdot 2500 = 3750\,000 \text{ mm}^2$

$I_x = 1500 \cdot 2500^3/12 = 1{,}95 \cdot 10^{12} \text{ mm}^4$

$I_y = 2500 \cdot 1500^3/12 = 0{,}70 \cdot 10^{12} \text{ mm}^4$

$$P_i \cdot \frac{E_s}{E_c} = A_s \cdot \sigma_{prestress} \cdot \frac{E_s}{E_c}$$

from (a): $1000\text{ MPa} - 20\text{ MPa} = 980\text{ MPa}$

$$= 8000 \cdot 980 \cdot \frac{200}{20} = 78{,}4 \cdot 10^6 \text{ N}$$

- Effect of tendon 2 on tendon 1 using (1):

$\delta\sigma_1 = -4{,}78 \text{ MPa}$

- Effect of tendon 3 on tendon 1 and 2:

$\delta\sigma_1 = -4{,}78 \text{ MPa}$ (same as previous)

$\delta\sigma_2 = 18{,}72 \text{ MPa.}$

	tendon 1	2	3
tendon 1	0	-4,78	-4,78
2	–	0	~~18,72~~ 18,72
3	–	–	0

[5p]

3 – 1

(c) stresses in tendons:

1. $980 + 2 \cdot (-4{,}78) = 970{,}4$ MPa

2. $980 + 1 \cdot (18{,}72) = 998{,}7$ MPa

3. $= 980$ MPa

$$P_{total} = A_1 \cdot \sigma_1 + A_2 \cdot \sigma_2 + A_3 \cdot \sigma_3$$

with $A_1 = A_2 = A_3 = 8000\ mm^2$

$$= 23{,}6 \cdot 10^6\ N$$

- Total prestress if no losses: $3 \times 8000 \times 1000 = 24{,}0 \cdot 10^6 N$

$\Rightarrow$ <u>1,7 %</u> prestress loss

2,5p

ENGINEERING TRIPOS PART IIB 2013
ASSESSOR'S REPORT, MODULE 4D7

The examination was taken by 16 candidates for Part IIB, plus 1 graduate student.

No scaling was required

Q1
A relatively straightforward question, well-answered by most candidates. Some students struggled with the units of the diffusion coefficient or used the 95%-percentile for the critical depth of the reinforcement.
Some students mentioned accidental and impact loads for part (c) whereas the question specifically asked for other deterioration mechanisms.

Q2
Clearly the hardest question. Most students struggled to derive the equations to solve for u and v or started with the wrong assumption that two bars were in the compression region leading to insufficient time to fully answer the question.
Part (c) was well answered by most students whereas some limited their answers to uni-axial bending and did not sketch the bi-axial bending interaction surfaces.

Q3
Part (a) was straightforward and well answered by most students. For part (b) some students did not account for the wedge pull-in losses already incurred in part (a) or only took these into account when answering part (c) which was acceptable but lead to the need for running the calculations twice.

P Desnerck (Principal Assessor)