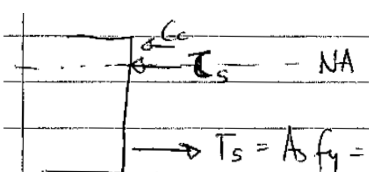
4D7 2018

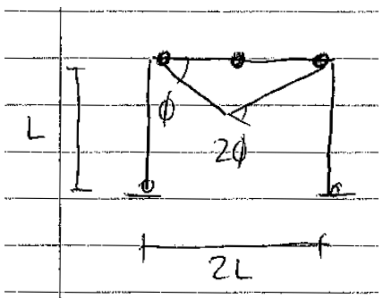
John Orr

1		Marks
(a)	Book work. Example paper questions 7 and 8 are relevant Assume: $f_{ct} = 0$ Plane section Simple stress-strain curves for steel and concrete Need to determine NA in order to calculate what the N+M values might be to give an interaction diagram • N/bhf_{cu} vs M/bh^2f_{cu} is conventional for axes • Assume various levels of strain in the section • Transform to stress • Calculate M+N • Usually calculate N_0 (strain in concrete = 0.0035) • M_{max} when concrete strain = 0.0035, steel strain = 0.0020 • M_0 when pure axial compression	30%
(b)	If $\varepsilon_y/\varepsilon_c \rightarrow 0$ then all steel yields (example question) plastic solution If not, then addition of steel depends on location relative to the NA and so the shape of the interaction diagram is altered (i.e. over reinforced and stress in steel is less yield stress at failure).	10%
(c)(i)	N = 0 All steel yields if on the NA, so since it is symmetrical then NA is at the position of the top steel  $T_s = A_s f_y = 339(475) = 161$ kN $C_c = 0.6(30)(150)(40) = 108$ kN Cs given as 0.60 in data book $\therefore C_s = 161 - 108 = 53$ kN. $M_u = C_c(15) + T_s(240) = 40.3$ kNm	10%

<table>
<tr><td>(c)(ii)</td><td>

Collapse in Beam Mode (other modes can be checked too)

WD = W.δ/2 = W.ϕ.L/2
ED = $M_u(4\phi)$
$M_u(4\phi)$ = W.ϕ.L/2
And M_u = 40.3kNm
Therefore:
W = 107.5kN
w = 107.5/6 = 17.9kN/m



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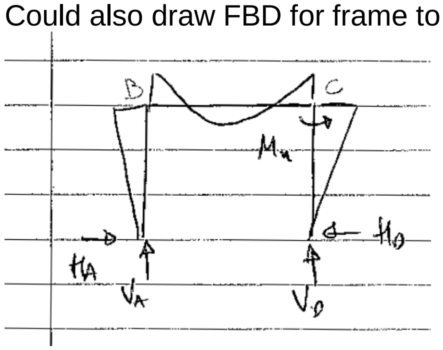
<tr><td>(c)(iii)</td><td>

Axial forces
M_u = 40.3kNm
Therefore $H_D = H_A$ = 40.3/L = 13.4kN
Moments about A gives vertical reactions = 107.5/2 = 53.8kN
Axial force in BC = 13.4kN
Could also draw FBD for frame to check.



Axial force is added to the compression steel therefore
C_s = 53 + 13.4 = 66.4kN
C_c = 108kN
T_s = 161kN
Take moments about the CA
161(120) + 66.4(120) + 108(135) = 41.9kNm
New W = $8M_u/L$ = 112kN (4% difference).
New w = 18.6kN/m

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<tr><td>(iv)</td><td>

Anything sensible.

- Remove material where M is low
- Comment on change in failure mode
- Comment on shear capacity

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Question 1(a) was well answered in general. Some students did not describe how to plot an interaction diagram in sufficient technical detail (the need to calculate for various levels of strain in the section). Most students were able to identify how such a diagram is used in design. The key to Part 1(c) was recognising the location of the neutral axis to be on the line of the compression steel, which can be gleaned from the question. The use of plastic collapse mechanisms was well answered by those who attempted it, and all that was required was a simple three hinge collapse mechanism. The calculation of axial forces in the frame was not well answered, and many students got themselves into complex mathematics unnecessarily. The Moment of resistance calculated in Part (i) can be used to find the horizontal reactions and thus the axial force in BC. Sadly, not very many students at all attempted part (iv), for which almost any sensible response would have yielded full marks.

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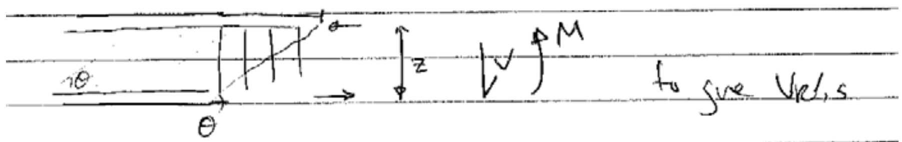
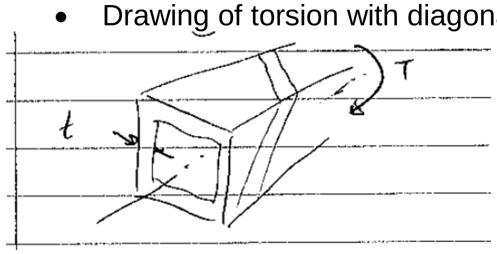
- Lower bound plasticity
- Cracked concrete at an angle θ carries compression
- Angle can be varied within certain limits
- Steel carries tension
- Drawing of a typical shear component, e.g.:



- Could discuss concrete contribution in context of EC2 not having one where transverse steel is present
- Drawing of torsion with diagonal struts, e.g:



- Shear and torsion by superposition, with same angle θ
- $T_{Ed} / T_{max} + V_{Ed} / V_{max} \leq 1.0$ (or comment to this effect)
- Comment on when this issue is likely e.g. hollow beams

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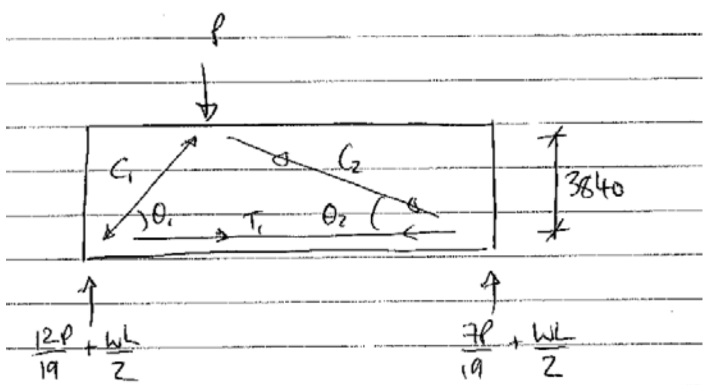
<tr><td>2(b)(i)</td><td>



- Choose any sensible geometry
- Angle depends on the depth chosen, 3840 is possibly too big

As drawn above:

- θ_1 = atan (3840/7000) = 29º
- θ_2 = atan (3840/12000) = 18º

C_2 = 7P/19sin18 = 1.19P (excluding self weight)
C_1 = 12P/19sin29 = 1.30P (excluding self weight)

T = C_2cos18

Strut width at the right hand side (see figure below) = 428mm

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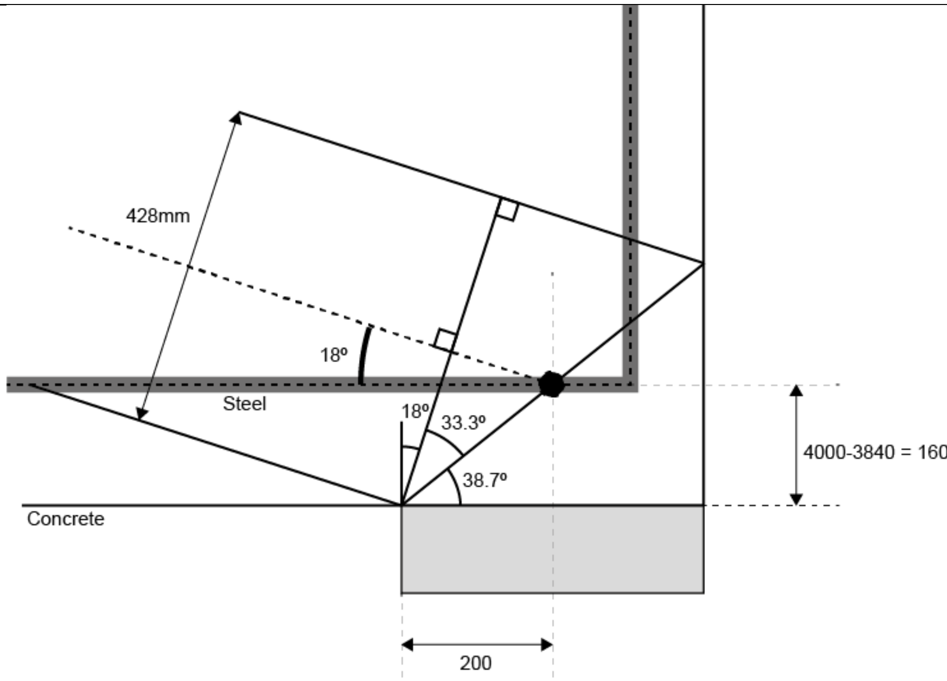

$\sigma_{Rd,max}$ = 0.6 (1-40/250)40 = 20.16MPa

For C_2
1.19P = 20.2(250)(428)
P = 1813kN (excluding s.w.)

Check T = C_2 cos (18) = 1724kN

- $A_s f_y$ = 575 x 6300 = 3623kN > T (therefore T not yielding)

Could also include selfweight
C_2sin18 = 7P/19 + 223kN
20.16(428)(250)sin18 = 7P/19 + 223
P = 1204kN

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<tr><td>2(b)(iii)</td><td>

2.5 times bigger!

- Node steel force (not yielding)
- Nodes not checked
- Strut limit is not the only consideration
- Most models limit strains at the nodes

If P = 685kN
C_2 = 1.19P
T = 1.19Pcos18 = 775kN
σ = 123MPa
Steel strain = 0.0006 at failure (very brittle).

Could also discuss how to model self weight.

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Question 2(a) was well answered although some students did not draw free body diagrams as asked, and some students did not talk about torsion, as asked in the question. Part 2(b) was more variable. The question required only that a feasible strut and tie model be drawn, with a three-member solution being the simplest. Some students over-complicated their answer, but this did not necessarily lose marks provided it was a feasible solution. Most students who attempted this question made sensible geometrical assumptions as to the shape of the strut and tie model, and were able to apply the equation given in Part 2(b)(ii). Part (iii) answers were more variable, with some students not making any comments at all on their calculations.

Solutions Q3 (a) Bookwork. - taken from notes.

Candidates are required to provide examples of 3 failures. MUST BE CONCRETE STRUCTURES

Various failures were discussed in lectures.

1. Ronan Point; 2. Palau Bridge; 3. Murrah Building 4. Stepney School Roof 5. Ferrybridge Colling Tower 6. Sleipner A Oil Platform 7. Millennium Tower 8. Citicorp Building 9. Nimitz Freeway 10. Kufstein Bridge 11. Tasman Bridge 12. Montreal Overpass

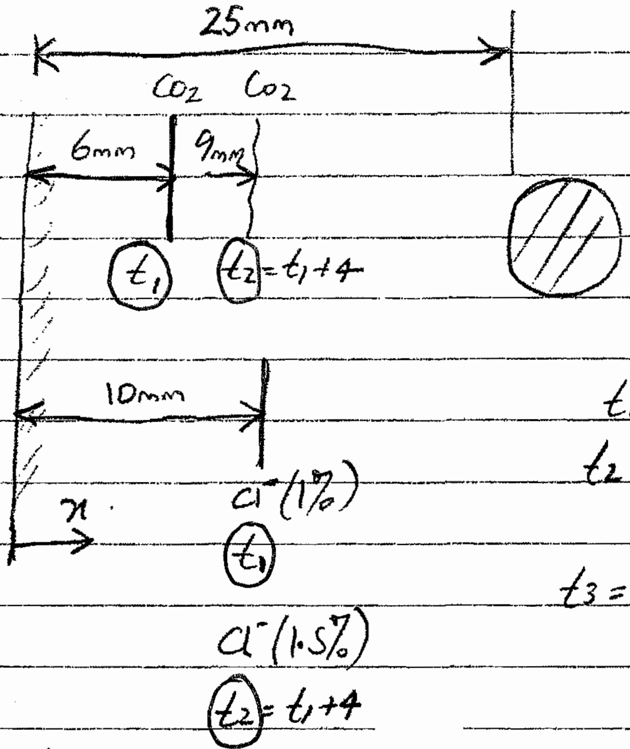
Some detailed notes on a few examples:-

Ronan Point tower block collapse, where a relatively minor gas explosion led to progressive collapse of parts of a tower block caused by inadequate tying-together of wall and floor precast units. It led directly to requirements to prevent collapses of structures that were out of proportion to the original failure (disproportionate collapse). Changing the factors of safety on the codes would not have made much difference.

Ferrybridge Cooling Towers, several of which collapsed under high, but not excessive winds. The designers had used a wind speed lower than the BS, and had not made any allowance for gusts, or for disturbances to the flow caused by the grouping of the towers. There was also inconsistent application of load factors (factoring the resulting stress, which was the difference of two components, rather than applying factors in the worst sense to the individual load elements).

Montreal Overpass Bridge in Canada which failed when a brittle shear failure propagated from a half joint through a cantilever. There were inadequacies in the original design (especially in the absence of shear steel), the construction quality management, and in the poor inspection and maintenance regime. Higher safety factors would have made a difference provided shear steel had been included.

2018 Q3(b)



t_1 = Time of 1st inspection

t_2 = " " 2nd inspection $= t_1 + 4$ years.

t_3 = time at which carbonation reaches steel at $x_3 = 25$mm

Carbonation

(i) $x \propto \sqrt{t}$

$$6 = k\sqrt{t_1} \Rightarrow k = 6/\sqrt{t_1}$$

$$9 = k\sqrt{t_2} \Rightarrow k = 9/\sqrt{t_2} = \frac{9}{\sqrt{t_1+4}}$$

$$25 = k\sqrt{t_3}$$

$$t_3 = \left(\frac{25}{k}\right)^2$$

$$t_3 = \left(\frac{25}{3.354}\right)^2 = \underline{55.6\text{yrs}}$$

$$\frac{2\cancel{6}}{\sqrt{t_1}} = \frac{\cancel{9}3}{\sqrt{t_1+4}}$$

$$\frac{4}{t_1} = \frac{9}{t_1+4}$$

$$4t_1 + 16 = 9t_1$$

$$5t_1 = 16$$

$$t_1 = 16/5 = 3.2\text{ years} \Rightarrow t_2 = 7.2\text{ years.}$$

$$k = \frac{6}{\sqrt{3.2}} = \underline{3.354}$$

∴ Time after 2nd inspection is:

$$T = 55.6 - (3.2 + 4)$$

$$= 55.6 - 7.2$$

$$\boxed{= 48.4\text{ years}}$$

(ii) Chloride s $\quad C = C_0(1-\mathrm{erf}(z)) \qquad z = \dfrac{x}{2\sqrt{Dt}}$

$$\frac{1}{1.5} \;\frac{= C_0(1-\mathrm{erf}(Z_1))}{= C_0(1-\mathrm{erf}(Z_2))} \qquad \text{At given } x;\; z_i \propto \frac{1}{\sqrt{t_i}}$$

$$1.(1-\mathrm{erf}(Z_2)) = 1.5(1-\mathrm{erf}(Z_1))$$

$$f(z) = 1.5\,\mathrm{erf}(Z_1) - \mathrm{erf}(Z_2) - 0.5 = 0 \qquad (1)$$

$$Z_1 \propto \frac{1}{\sqrt{t_1}} \;; \quad Z_2 \propto \frac{1}{\sqrt{t_2}}$$

$$\therefore \frac{Z_1}{Z_2} = \frac{\sqrt{t_2}}{\sqrt{t_1}} = \frac{\sqrt{7.2}}{\sqrt{3.2}} = 1.5 \qquad \therefore Z_1 = 1.5 Z_2$$

Solve for Z_1 & Z_2 by trial & error.

Guess 1/ $Z_2 = 0.2 \quad Z_1 = 1.5\times 0.2 = 0.3$; $f(z) = 1.5\times 0.33 - 0.22 - 0.5$
$\mathrm{erf}(Z_2) = 0.22 \quad \mathrm{erf}(Z_1) = 0.33 \qquad = -0.225 \neq 0.$

2/ $Z_2 = 0.4 \quad Z_1 = 0.6$
$\mathrm{erf}(Z_2) = 0.43 \quad \mathrm{erf}(Z_1) = 0.60$; $f(z) = 1.5\times 0.60 - 0.43 - 0.5$
$= -0.03 \neq 0.$

3/ $Z_2 = 0.44 \quad Z_1 = 0.66$
$\mathrm{erf}(Z_2) \simeq 0.47 \quad \mathrm{erf}(Z_1) \simeq 0.65$; $f(z) = 1.5\times 0.65 - 0.47 - 0.5$
$= 0.005 \simeq 0.$

i.e. $Z_1 = 0.66$ at $t_1 = 3.2$ years
$Z_2 = 0.44$ at $t_2 = 7.2$ years. } at $x = 10$mm.

Require $Cl^- = 0.4$ at $x = 25$mm.

$$\frac{1}{0.4} \;\frac{= C_0(1-\mathrm{erf}(Z_1))}{= C_0(1-\mathrm{erf}(Z_3))} \qquad \text{where } \mathrm{erf}(Z_1) \simeq 0.65$$

$$\Rightarrow 1-\mathrm{erf}(Z_3) = 0.4(1-0.65) \;\Rightarrow \mathrm{erf}(Z_3) = 1-0.14 = 0.86.$$

2018 Q3b(ii) cont.

From tables $Z_3 \simeq 1.1$

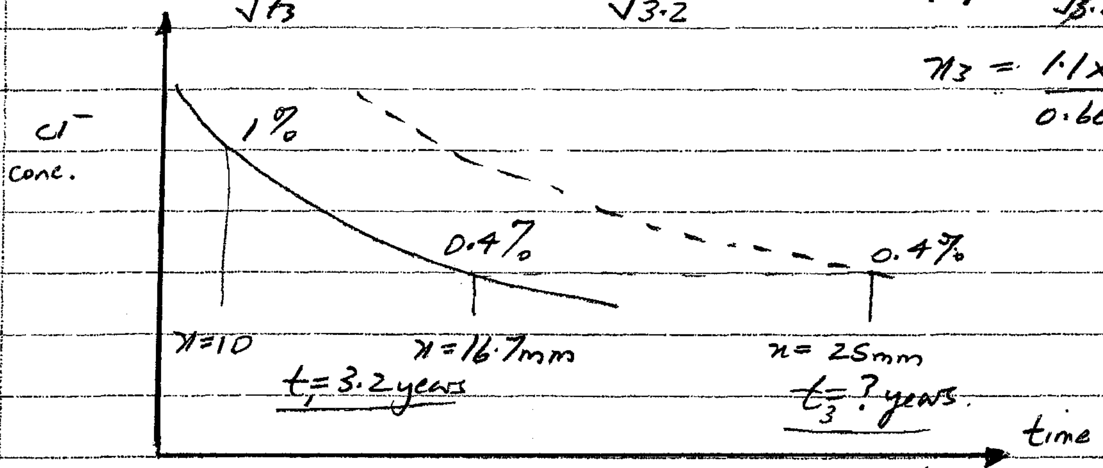
Have 1% Cl^- at $x_1 = 10$mm. $\qquad Z = \frac{kx}{\sqrt{t}}$

" 0.4% Cl^- at $x_3 = ?$mm

$Z_1 = \frac{k x_1}{\sqrt{t_1}}$ $\qquad 0.66 = k \times \frac{10}{\sqrt{3.2}}$

$Z_3 = \frac{k x_3}{\sqrt{t_3}}$ $\qquad 1.1 = k \frac{x_3}{\sqrt{3.2}}$ $\qquad \therefore \frac{0.66}{1.1} = \frac{10}{\cancel{\sqrt{3.2}}} \frac{\cancel{\sqrt{3.2}}}{x_3}$

$x_3 = \frac{1.1 \times 10}{0.66} = \underline{16.67\text{m}}$



Penetration of Cl^- is $\propto \sqrt{t}$. i.e. $x = k\sqrt{t}$.

$16.7 = k\sqrt{3.2}$

$x_3 = k\sqrt{t_3}$

$\frac{x_3}{x} = \frac{\sqrt{t_3}}{\sqrt{t_1}} \Rightarrow \frac{25}{16.7} = \frac{\sqrt{t_3}}{\sqrt{3.2}}$

$\therefore t_3 = 3.2 \times \left(\frac{25}{16.7}\right)^2 = 7.2$ years

$\Rightarrow$ $t_3 = 7.2$ years until chloride % = 0.4% at level of steel.

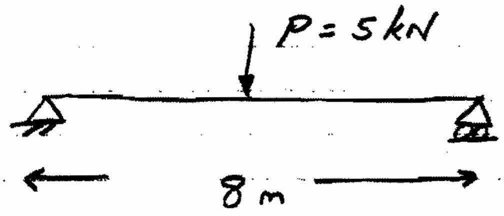
$\Rightarrow$ Time after 2nd inspection is $7.2 - 7.2 = \underline{0}$ years. c.f. 48.4yrs for carbonation.

$\Rightarrow$ Chlorides critical for corrosion.

Question 3(a) required students to describe the primary causes of failure and provide insight into the implications of 3 examples of failure of concrete structures from amongst the many presented in the lecture course. Nearly all could name three examples but not all could identify the root cause or causes of the failure. Full marks were obtained by those who actually answered the 3 questions asked i.e. identify the causes, discuss implications for codes of practice and explain whether the failure could have been avoided if larger factors of safety were used. Surprisingly few were able to address all these issues for each of the structures chosen. Too often the cause was couched in vague terms, e.g. a gas explosion for Ronan Point rather than identifying the lack of continuity ties, robustness and redundancy in the precast panelised structure as being the root cause.

Part 3(b) required candidates to use the inspection test data given to predict the time to initiation of corrosion due to carbonation and chloride ingress. This was well answered my most candidates and this is reflected in the somewhat higher average mark for this question compared to the others. A few dived into calculations without actually stating what they were evaluating, and others forgot to identify which deterioration mechanism was more critical. A few decided not to interpolate the table of error function values even though this was quite straightforward.

Q4(b)(i)



$M_P = 5$ kN

Strength (Resistance)

$M_R = 40$ kNm.

Load effect (Stress resultant)

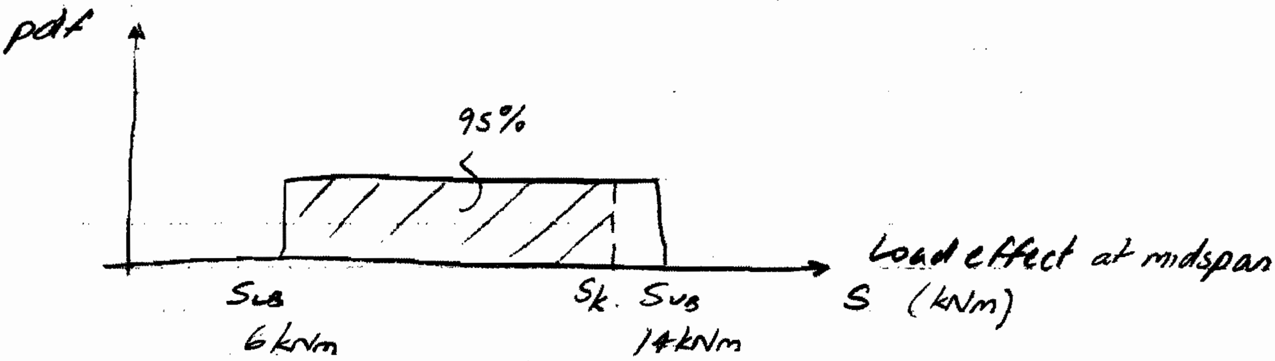
$S = \frac{PL}{4} = \frac{5 \times 8}{4} = 10$ kNm.

Range for load effect. (Lower + Upper bound)

$S_{LB} = \frac{3 \times 8}{4} = 6$ kNm

$S_{UB} = \frac{7 \times 8}{4} = 14$ kNm

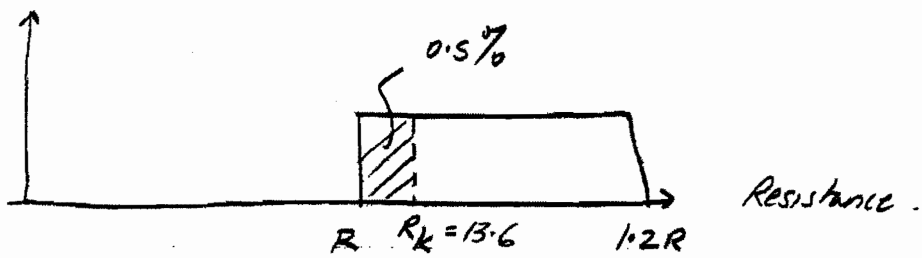
(i)



Characteristic Load Effect

$S_k = 6 + 0.95(14-6) = 13.6$ kNm

(ii) Resistance (Strength).



$R_k = 0.05 \times (1.2R - R) + R = 13.6$

$1.01R = 13.6$.

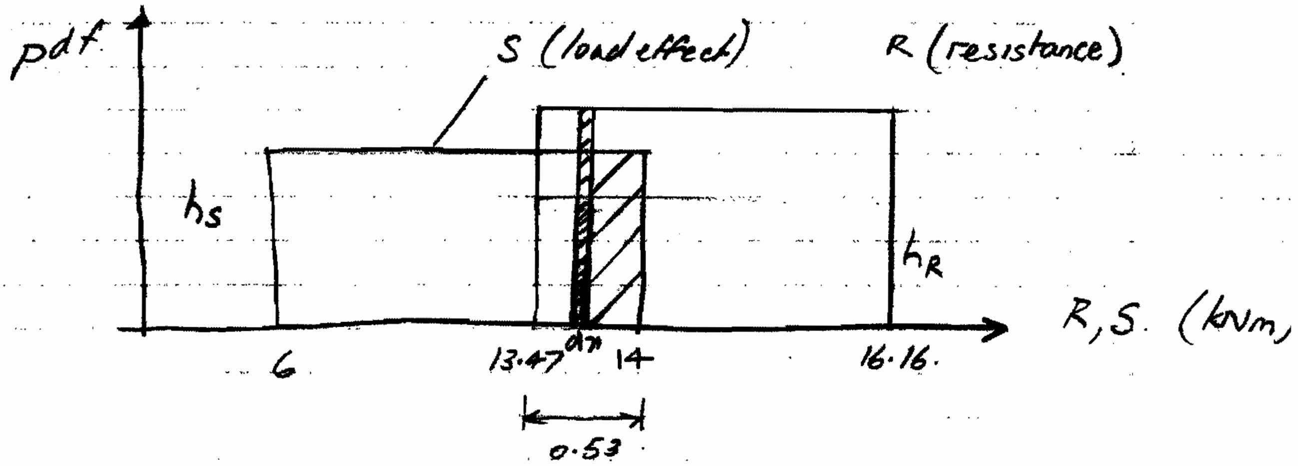
Lower limit $R = \frac{13.6}{1.01} = 13.47$ kNm.

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

Q4 (b)(ii) (cont.)

Probability failure

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



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.

$$P(x \leq R \leq x + dx) = h_R . dx = 0.3717 \, dx$$

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

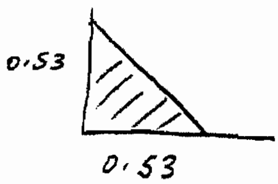
$$P(S \geq x) = (14 - x) h_S = 0.125(14 - x)$$

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

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

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

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



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

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

Question 4(a) was again predominantly bookwork and well answered by the vast majority of students although again, precise statements covering all the question's parts were required to obtain full marks. The most common error in Part 4(a)(i) was to describe different types of *concrete* rather than *cement replacement materials*. Part 4(a)(ii) then went on to ask about 4 different types of cement. Most could name these but not all managed to explain how the changed properties compared to OPC were achieved. The remaining parts of Part 4(a)(i) were quite well covered by most candidates.

Part 4(b) was a straight forward reliability question examining the probability of failure of a simple RC beam in bending which was generally well answered by most candidates. Surprisingly few sketched the overlapping pdf's of load effect and resistance or explicitly wrote out the convolution integral but none the less most went on to attempt the integration, which was generally well done.