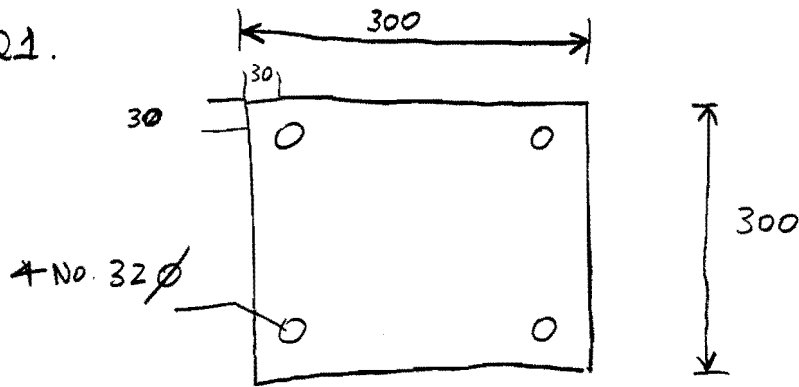


Q1.



$$f_{cd} = 25 \text{ MPa}$$

$$f_{sy} = 460 \text{ MPa}$$

$$E_{cu} = 0.0035$$

$$E_y = 0.002$$

$$\sigma = 0.6 f_{cd} = 0.6 \times 25 = 15 \text{ MPa}$$

at ULS.

(a) Pure axial load.

$$\sigma = \frac{F}{A}$$

$$N_u = (0.6 \times f_{cd}) \times A_c + A_s \cdot f_y$$

$$= 0.6 \times 25 \times (300 \times 300 - 4 \times \frac{\pi \cdot 32^2}{4}) + 4 \times \frac{\pi \cdot 32^2}{4} \times 460$$

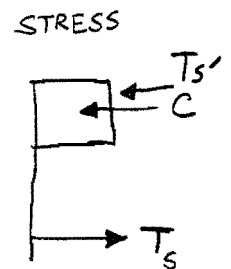
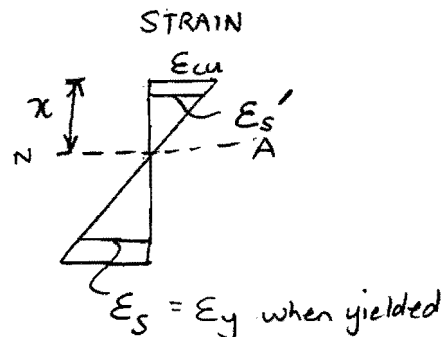
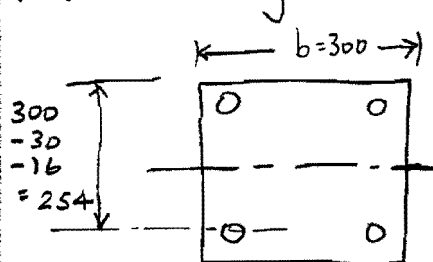
$$= 1.30 \times 10^6 + 1.48 \times 10^6$$

$$= \underline{2.78 \times 10^6 \text{ N}} \quad (2782 \text{ kN})$$

[10%]

(If area of bars not deducted from A_c , get $N_u = 2.83 \times 10^6 \text{ N}$)

(b) Bending about X-X axis



$$\text{Balanced failure} \Rightarrow E_{cu} = 0.0035 \quad \& \quad E_s = E_y = 0.002$$

Find neutral axis, ξ .

$$\frac{E_{cu}}{\xi} = \frac{E_y}{(d - \xi)}$$

$$\therefore 0.0035(254 - \xi) = 0.002 \xi$$

$$0.889 = 0.0055 \xi$$

$$\underline{\xi = 161.6 \text{ mm}}$$

Q1(cont.) Check if compression steel has yielded (i.e. if $\epsilon_s' \geq \epsilon_y$)

$$\frac{\epsilon_s'}{161.6 - (30 + 16)} = \frac{0.0035}{161.6}$$

$$\Rightarrow \epsilon_s' = 0.0025 > \epsilon_y \Rightarrow \text{compression steel has fully yielded.}$$

$$\begin{aligned} M &= 0.6 f_{cd} \cdot b \cdot x \cdot \left(150 - \frac{x}{2}\right) + 2 \cdot A_s \cdot f_y \cdot (150 - 46) \times 2 \\ \text{about} & \\ \text{X-X} & \\ &= 0.6 \times 25 \times 300 \times 161.6 \times \left(150 - \frac{161.6}{2}\right) + 2 \cdot \frac{\pi \cdot 32^2}{4} \times 460 \times 104 \times 2 \\ &= 50.32 \times 10^6 + 153.9 \times 10^6 \\ &= \underline{204.2 \times 10^6 \text{ Nmm}} \quad (204.2 \text{ kNm}) \end{aligned}$$

< tension & comp. steel

Axial Force

$$N = 0.6 f_{cd} \left(b x - 2 \cdot \frac{\pi \cdot 32^2}{4} \right)$$

steel bars in compression (this only makes a small difference to axial load calc.)

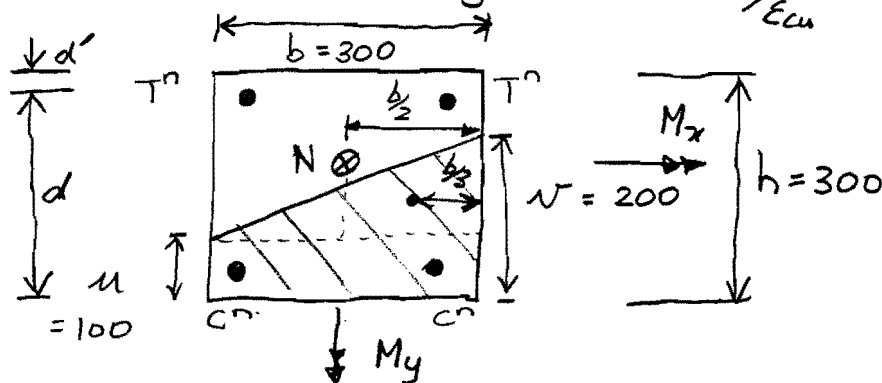
$$= 0.6 \times 25 \left(300 \times 161.6 - 2 \cdot \frac{\pi \cdot 32^2}{4} \right)$$

$$= 15 \left(48.48 \times 10^3 - 1.61 \times 10^3 \right)$$

$$= \underline{703 \times 10^3 \text{ N}} \quad (703 \text{ kN})$$

[40%]

(c) Biaxial Bending



$\frac{\epsilon_y}{\epsilon_{cu}}$ small. \Rightarrow assume all steel has yielded.

From lecture notes: Axial force $N = 0.6 f_{cd} \left[b u + \frac{1}{2} b \cdot (v - u) \right]$

+ Moments $M_y = 0.6 f_{cd} \left[\frac{1}{2} b (v - u) \right] \cdot \frac{b}{6}$

cont.

$$M_x = 2A_b f_{yd} (d-d') + 0.6 f_{cd} \left[bu \left(\frac{h}{2} - \frac{u}{2} \right) \right] \\ + 0.6 f_{cd} \cdot \frac{1}{2} b (v-u) \left[\frac{h}{2} - u - \frac{1}{3} (v-u) \right]$$

where h = overall depth of section (= b here)
 A_b = area of single bar

Axial force

$$N = 0.6 f_{cd} \left[b \cdot u + \frac{1}{2} b \cdot (v-u) \right] \\ = 0.6 \times 25 \left[300 \times 100 + \frac{1}{2} \times 300 \times 100 \right] \\ = \underline{675 \times 10^3 \text{ N}} \quad (675 \text{ kN})$$

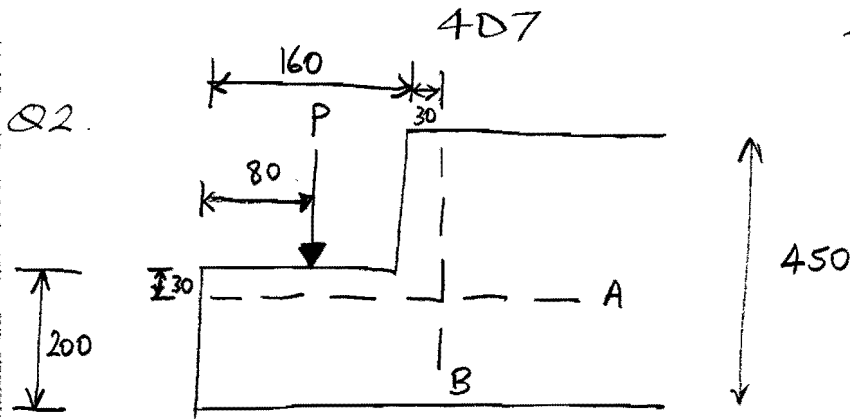
Moments

$$M_y = 0.6 \times 25 \times \left[\frac{1}{2} \times 300 (200-100) \right] \cdot \left(\frac{300}{6} \right) \\ = \underline{11.25 \times 10^6 \text{ Nmm}} \quad (11.25 \text{ kNm})$$

$\frac{b}{2} - \frac{b}{3} = \frac{b}{6}$

$$M_x = 2 \cdot \frac{\pi 32^2}{4} \times 460 (254 - 46) \\ + 0.6 \times 25 \left[300 \times 100 (150 - 50) \right] \\ + 0.6 \times 25 \cdot \frac{300}{2} (200 - 100) \left[150 - 100 - \frac{1}{3} (200 - 100) \right] \\ = 153.9 \times 10^6 + 45 \times 10^6 + 3.75 \times 10^6 \\ = \underline{202.7 \times 10^6 \text{ Nmm}} \quad (202.7 \text{ kNm})$$

[50%]



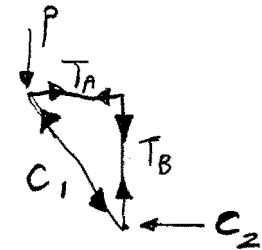
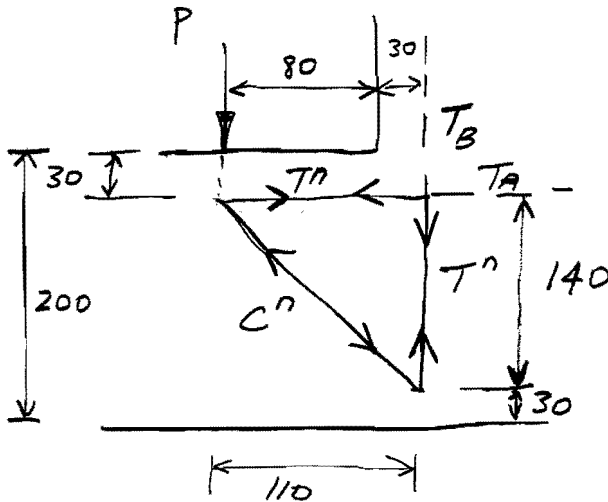
$f_{yd} = 460 \text{ MPa}$

a(i) R/F A $10 \phi @ 100 \text{ mm}$

$$A_b = \frac{\pi \cdot 10^2}{4} = 78.5 \text{ mm}^2 \text{ (1 bar)}$$

$$A_s = 78.5 \times \frac{1000}{100} = 785 \text{ mm}^2/\text{m} \text{ per metre length.}$$

Assume strut & tie model - force path.



$$T_A = A_s \times f_y = 785 \times 460 = 361.1 \times 10^3 \text{ N} = \frac{361.1 \text{ kN}}{\text{per metre length}}$$

$$\frac{T_A}{P} = \frac{110}{140} \Rightarrow P = 361.1 \times \frac{140}{110} = 459.6 \text{ kN per metre length.}$$

$T_B = P = 459.6 \text{ kN per metre.}$

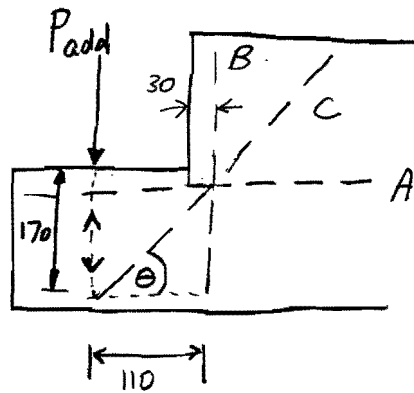
$$\sigma = \frac{T}{A} \therefore T = \sigma \cdot A$$

\Rightarrow Require A_s per metre of $\frac{P}{f_y} = \frac{459.6}{460} \approx 1000 \text{ mm}^2/\text{m}$.

For B adopt $12 \text{ mm } \phi$ bars @ 100 mm centres gives $113.1 \text{ mm}^2/\text{bar}$
 $\Rightarrow 1131 \text{ mm}^2/\text{m} @ 100 \text{ centres.}$

Q2 (cont.)

a(ii)



Add bars C to take additional load at P.

$$\tan \theta = \frac{170}{110}$$

$$T_c \sin \theta = P_{add}$$

For C bars $10\text{mm } \phi$ @ 100mm spacing $T_c = 785 \times 460$
 mm^2/m MPa
 $= 361.3 \text{ kN/m}$

$$\therefore P_{add} = 361.3 \times \sin 57.04^\circ = 303.3 \text{ kN}$$

$$\therefore \text{Total } P = 459.6 + 303.3 = \underline{\underline{762.9 \text{ kN/m}}}$$

- a(iii)
- Use of strut & tie method - lower bound
 - Need to check strength of concrete struts;
 find widths; concrete carries compression
 - Also need to ensure nodal zones have sufficient capacity
 - Anchorage of steel is sufficient
 - Check bars fit (sufficient spacing between bars)

Q2 (b) Main anhydrous compounds in cement

		<u>Symbol</u>
Tricalcium Silicate	$3\text{CaO} \cdot \text{SiO}_2$	C_3S (54%)
Dicalcium Silicate	$2\text{CaO} \cdot \text{SiO}_2$	C_2S (17%)
Tricalcium Aliminate	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$	C_3A (11%)
Tetracalcium Aluminoferrite	$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	C_4AF (9%)

Hydration process

Anhydrous compounds plus gypsum mixed with water to form unstable supersaturated solution from which calcium silicate and aluminate hydrates precipitate. This is an exothermic reaction.

Main reactions

In simple terms there are two main groups of reactions taking place during the hydration of Portland cement. The first is fast, occurring in the first 4 hours, and causes the cement to *set*. It is the hydration of C_3A , which also generates heat.

The second is slower, and causes cement to *harden*. It starts after a delay of 10 hours or so, and takes 100 days or more before it is complete. It is the hydration of C_2S and C_3S to *tobomorite* gel, the main bonding material which occupies 70% of the structure.

Unwanted materials

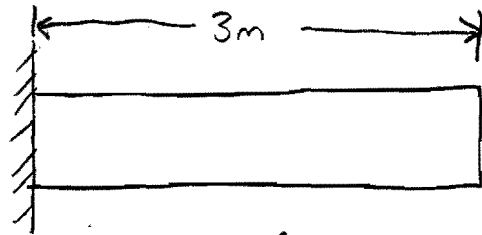
Ettringite (calcium sulfo aluminium hydrate) has a bigger volume than its constituents. When the concrete is still fresh the matrix can deform and accommodate this expansive product. (Note that when it forms in hardened concrete the expansive nature of ettringite can lead to cracking).

C_3A makes cement set and harden too quickly and is thus an unwanted component.

	Anhydrous Compounds	Rate of hydration	Heat Evolved	Strength contribution	Comment
Structural compounds	C_3S	Moderately fast	Considerable over long period	1 – 28+ days	Most important to strength
	C_2S	More slowly	Slow	14 – 28+ days	Some further contribution to strength after 28 days
Unwanted materials	C_3A	Very rapid	Very considerable	Up to 1 day	Flash set avoided by addition of gypsum
	C_4AF	Slow	Little	No cementing properties	

Table Characteristics of hydration products of Portland Cement

Q3. (a)



Short term loading.

$$f_{ct} = 3 \text{ MPa.}$$

Turn A_s upside down

250



400



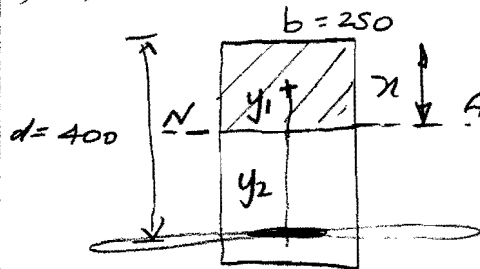
450

 $A_s = 2000$

$$E_c = 30 \text{ GPa.}$$

$$E_s = 210 \text{ GPa}$$

$$m = \frac{E_s}{E_c} = 7$$

(a)(i) Cracked second moment of area I_{cr} (using no-tension theory).

Transform steel to equivalent concrete.

$$mA_s = 7 \times 2000 = 14000 \text{ mm}^2$$

Use see-saw analogy. (1st moment of area about NA)

$$b \cdot x \cdot \frac{x}{2} = mA_s (d - x)$$

$$\frac{bx^2}{2} = mA_s d - mA_s x$$

$$\Rightarrow \frac{250x^2}{2} + 7 \cdot 2000 \cdot x - 7 \cdot 2000 \cdot 400 = 0.$$

$$25x^2 + 2800x - 2800 \times 400 = 0.$$

$$x^2 + 112x - 44800 = 0.$$

$$x = \frac{-112 \pm \sqrt{112^2 + 4 \cdot 1 \cdot 44800}}{2}$$

$$= \frac{-112 \pm 437.89}{2}$$

$$\text{NA } x = 162.94 \text{ mm (from compression face)} \quad [2]$$

$$I_{cr} = \frac{bx^3}{12} + \overbrace{b \cdot x \cdot (y_1)}^{A_{conc}} + (mA_s)(y_2)^2$$

$$I = \int y^2 dA$$

Use parallel axes formula

$$= \left(\frac{250 \times 162.94^3}{12} \right) + (250 \times 162.94) \left(\frac{162.94}{2} \right)^2$$

$$I_{new} = I_{old} + A \times \text{shift}^2$$

$$+ (7 \cdot 2000) (400 - 162.94)^2$$

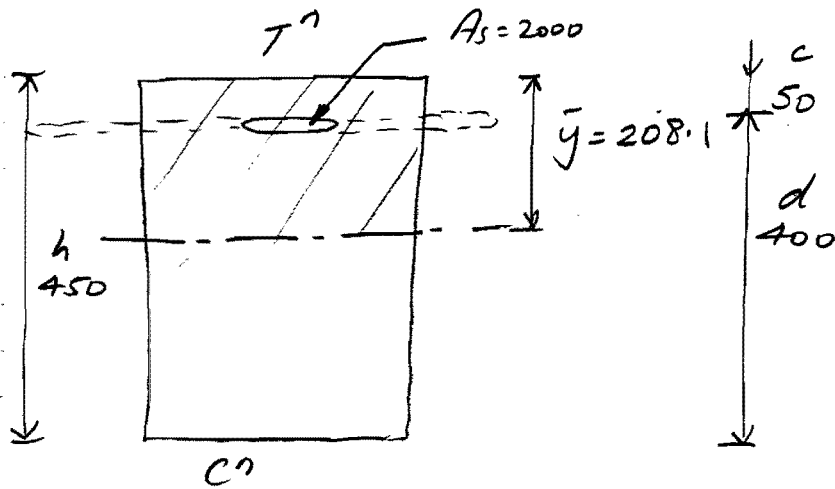
$$= 90.13 \times 10^6 + 270.38 \times 10^6 + 786.74 \times 10^6$$

$$\therefore I_{cr} = 1.147 \times 10^9 \text{ mm}^4$$

[4]

407 2014-15 4th p9
 Q3(a)(ii) Find tip deflection δ_{tip} given $I_{un} = 1.94 I_G$

for $M_{applied} = 50 \text{ kNm}$ & distance from tension face (base) to centroid is 208.1 mm .



$$M = 50 \text{ kNm}$$

$$I_{un} = 2230 \times 10^6 \text{ mm}^4$$

From data sheet $\xi = 1 - \beta \left(\frac{\sigma_{sr}}{\sigma_s} \right)^2$ (or $\xi = 1 - \beta \left(\frac{M_{sr}}{M_s} \right)^2$)

Moment to cause 1st cracking

$$\sigma_t = \frac{M_{cr} \cdot y}{I_{un}} \Rightarrow M_{cr} = \frac{\sigma_t \cdot I_{un}}{y} = \frac{3 \times 2230 \times 10^6}{208.1} = 32.1 \times 10^6 \text{ Nmm}$$

(32.1 kNm) [2]

Stress in steel in cracked section due to moment to cause 1st cracking

$$\sigma_{sr} = \frac{M_{cr} \cdot y}{I_{cr}} = \frac{32.1 \times 10^6 \times 208.1}{1147 \times 10^6} = 5.82 \text{ N/mm}^2$$

Stress in steel in cracked section due to full applied moment $M = 50 \text{ kNm}$.

$$\sigma_s = \frac{M \cdot y}{I_{cr}} = \frac{50 \times 5.82}{32.1} = 9.065 \text{ N/mm}^2$$

$$\xi = 1 - 1.0 \left(\frac{5.82}{9.07} \right)^2 = 0.588 \text{ [2]} \text{ (can also do this using moments } M_{cr} \text{ \& } M \text{)}$$

In data sheet, $\alpha = K$.

$$K = \xi K_{cr} + (1 - \xi) K_{un}$$

$$K_{cr} = 1.45 \times 10^{-6}$$

$$K_{un} = 0.747 \times 10^{-6}$$

$$= \frac{M}{E_c} \left[\frac{\xi}{I_{cr}} + \frac{(1 - \xi)}{I_{un}} \right] = \frac{50 \times 10^6}{30 \times 10^3} \left[\frac{0.588}{1147 \times 10^6} + \frac{(1 - 0.588)}{2230 \times 10^6} \right]$$

$$= 1667 \left(5.126 \times 10^{-10} + 1.848 \times 10^{-10} \right) = 1.16 \times 10^{-6}$$

Q3 (a)(ii) (cont.)

$$K = -\frac{d^2 V}{dx^2}$$

Massumed constant.

$$\Rightarrow \frac{dV}{dx} = Kx + A.$$

$$\text{BCs At } x=0, \frac{dV}{dx} = 0 \Rightarrow A=0.$$

$$V = \frac{Kx^2}{2} + B.$$

$$\text{At } x=0 \quad V=0 \Rightarrow B=0.$$

[2]

Tip deflection $V = \frac{KL^2}{2} = \frac{1.16 \times 10^{-6} \times 3000^2}{2} = \underline{5.22 \text{ mm}}$

$$\frac{L}{250} = 12 \text{ mm}$$

$$\frac{L}{500} = 6 \text{ mm}$$

 \Rightarrow Beam ok for serviceability.

$$\delta = \frac{ML^2}{2EI} = \frac{KL^2}{2EI}$$

$$K = \frac{M}{EI}$$

Alternative approach.

$$\delta_{cr} = \frac{50 \times 10^6 \times 3000^2}{2 \times 30 \times 10^3 \times 1147 \times 10^6} = \underline{6.54 \text{ mm}}$$

$$\delta_{un} = 6.54 \times \frac{1147}{2230} = 6.54 \times 0.514 = \underline{3.36 \text{ mm}}$$

$$\delta_{tip} = \xi \delta_{cr} + (1-\xi) \delta_{un}$$

$$= 0.588 \times 6.54 + (1-0.588) \times 3.36$$

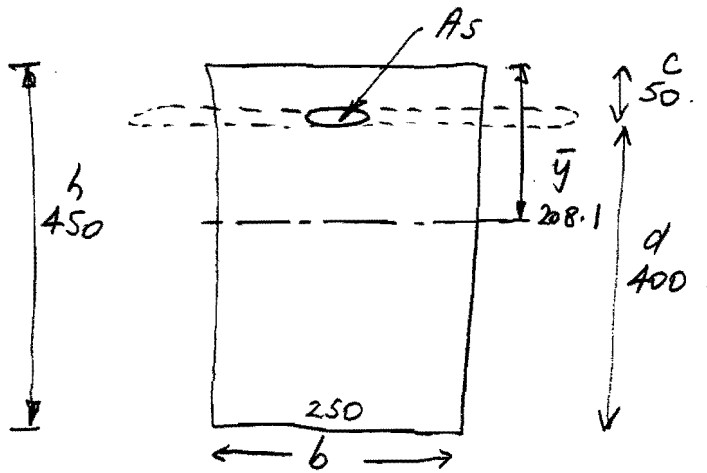
$$= 3.84 + 1.384$$

$$= \underline{5.23 \text{ mm}}$$

Show. $I_{un-cracked} = 1.94 I_{cracked}$

$$I = \int y^2 dA$$

Use parallel axes theorem



$$I_{un} = \left[\frac{b \bar{y}^3}{12} + b \bar{y} \times \left(\frac{\bar{y}}{2} \right)^2 \right] + (m-1) A_s (\bar{y} - 50)^2$$

Concrete in compression

$$+ \left[\frac{b (h - \bar{y})^3}{12} + b (h - \bar{y}) \times \left(\frac{h - \bar{y}}{2} \right)^2 \right]$$

$$= \frac{250 \times (208.1)^3}{12} + 250 \times 208.1 \times \left(\frac{208.1}{2} \right)^2 + (7-1) 2000 (208.1 - 50)^2$$

$$+ \frac{250 (450 - 208.1)^3}{12} + 250 (450 - 208.1) \left(\frac{450 - 208.1}{2} \right)^2$$

$$= 187.7 \times 10^6 + 563.2 \times 10^6 + 299.9 \times 10^6 + 299.9 \times 10^6 + 884.6 \times 10^6$$

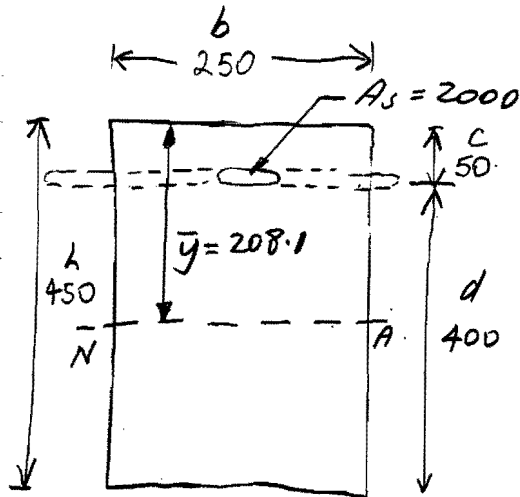
$$= 2230.5 \times 10^6 \text{ mm}^4$$

$$I_{un} = 2230 \times 10^6 \text{ mm}^4$$

$$I_{cr} = 1147 \times 10^6 \text{ mm}^4$$

$$\frac{I_{un}}{I_{cr}} = 1.94$$

11-03



Can't lower - expect r/f at top.

Usually measure distance to NA, \bar{y} from tension flange. $m = \frac{E_s}{E_c} = 7$

Find NA for uncracked section

$$A_c \bar{y} = \sum A_i y_i$$

$$\bar{y} = \frac{\sum A_i y_i}{A_c}$$

Take moments of area about tension face.

$$\bar{y} = \frac{b \times h \times \frac{h}{2} + (m-1) \times A_s \times c}{b \times h + (m-1) A_s}$$

$$= \frac{250 \times 450 \times \frac{450}{2} + (7-1) \times 2000 \times 50}{250 \times 450 + (7-1) 2000}$$

$$= \frac{\overset{\textcircled{1}}{25.3 \times 10^6} + \overset{\textcircled{2}}{0.6 \times 10^6}}{\overset{\textcircled{3}}{112.5 \times 10^3} + \overset{\textcircled{4}}{12 \times 10^3}} = \frac{\overset{\textcircled{6}}{25.9 \times 10^6}}{\overset{\textcircled{5}}{124.5 \times 10^3}} =$$

$$\therefore \bar{y} = \underline{208.1 \text{ mm}}$$

Q3(b)

High Strength Concrete (HSC) / High Performance Concretes (HPC)

High strength or high performance concretes are those which have compressive strengths typically in the range of around 50 – 120 MPa. These are now quite widely used in construction, in particular for columns in high-rise buildings. Such strengths have been obtained by reducing the water-cement ratio, which has been made possible by the use of high doses of superplasticizer and, to a lesser extent, through the use of silica fume. In addition, compared with normal strength concrete, the cement content is usually slightly increased and the maximum size of the coarse aggregate is usually smaller.

Reactive Powder Concrete (RPC)

Recent developments in concrete technology have led to a new family of Portland cement based concretes that are essentially made of powders. Depending on the composition and the heat treatment to which they are subjected, *reactive powder concretes* (RPC) can achieve strengths of up to 200 MPa when cured in hot water (90°C) for three days. It is claimed that concretes have been produced in the laboratory with compressive strengths of up to 800 MPa when cured with dry heat at 400°C. The high strengths are achieved by:

- Improving the homogeneity of the mix by eliminating coarse aggregates.
- Improving the packing of the granular mix by carefully selecting the grain size of the different powders.
- Using the pozzolanic properties of highly refined silica fume and optimisation of the Portland cement chemistry to produce the highest strength hydrates.
- Pressing the concrete before and after setting so that the entrapped air can be eliminated as well as most of the chemical contraction accompanying hydration reactions
- Improving the microstructure after setting through a heat treatment that changes the nature of the hydrates formed
- Improving the ductility of the materials through the use of steel fibres.

Potential advantages of RPC

- RPC is claimed to be a better alternative to High Performance Concrete. It is also claimed to have the potential to structurally compete with steel.
- Its superior strength combined with higher shear capacity results in significant dead load reduction and limitless structural member shape.
- With its ductile tension failure mechanism, RPC can be used to resist all but direct primary tensile stresses. This eliminates the need for supplemental shear and other auxiliary reinforcing steel.
- Its low and non-interconnected porosity diminishes mass transfer making penetration of liquid/gas or radioactive elements nearly non-existent. Cesium diffusion is non-existent and Tritium diffusion is 45 times lower than conventional containment materials.

Potential Disadvantages of RPC

In a typical RPC mixture design, the least costly components of conventional concrete have been basically eliminated or replaced by more expensive elements. The fine sand used in RPC becomes equivalent to the coarse aggregate of conventional concrete, the Portland cement fills the role of the fine aggregate and the silica fume that of the cement. The mineral component optimisation alone results in a substantial increase in cost over and above that of conventional concrete (5 to 10 times higher than High Performance Concrete.)

Application

An application of RPC can be seen in the Pedestrian Bridge in the city of Sherbrooke, Quebec, Canada. RPC has also been used for isolation and containment of nuclear waste of several projects in Europe. It was also used for the specialist applications requiring very high strength concrete in confined locations in the anchorage blisters for the strengthening of Hammersmith flyover.

Fibre Reinforced Concrete

Fibre reinforced concrete has been used widely in recent years. Small fibres of steel or various synthetic materials are added to the mix and distributed throughout the concrete. This provides additional tensile strength to the concrete. It has been employed to reduce the extent of cracking and, in particular, to reduce shrinkage cracking.

Advantages - can be used to replace temperature steel near slab surface - it is not as susceptible to corrosion of reinforcing bars which can lead to spalling and delamination. Close spacing of fibres results in very fine crack pattern compared to conventional mesh and bar arrangements which may have spacing of, typically, 100mm.

Disadvantages - limited tensile capacity - still need primary steel in locations of high tensile forces as FRC is mainly used for temperature and shrinkage crack control. It can be difficult to get uniform distribution of fibres throughout mix. Can be costly.

Examples of Use in Practice - it has been employed to reduce the extent of cracking and, in particular, to reduce shrinkage cracking e.g. insitu overlays on concrete bridge decks, concrete floor slabs to reduce surface cracking.

Q4(a)

Consider 4 C's of concrete durability + H₂O.

1. Cement content
2. Cover
3. Compaction
4. Curing + W/C.

Cement content - wish to ensure adequate cement content to ensure strength + also so that sufficient binding matrix is available to hydrate, react + fill voids within composite aggregate/sand/cement mixture.

↓ permeability

↓ pore/capillary size

↑ alkalinity

- also promotes alkaline environment + hence passivation of reinforcing steel to reduce likelihood of corrosion.

- Want cement to be available to promote 'autogenous healing' of fine cracks.

Cover - provides protective barrier to ingress of deleterious materials (e.g. chlorides, carbonation)

protects r/f. from corrosion + fire

- ensures adequate bond to r/f. bars.

(should not be too large or may get spalling)

Compaction - provides dense, impermeable concrete by removing

↓ voids/air gaps

↓ permeability

air pockets/bubbles. This again assists in preventing ingress of corrosive materials toward r/f.

(Must avoid segregation from over-compaction)

Curing - essential to prevent drying out of exposed surface of

↓ Permeability

↓ rate of initiation of corrosion

concrete which can result in incomplete hydration reaction.

This may inhibit the closing of capillary pores within

the matrix, again allowing greater permeability to corrosive

materials. Similarly you may get surface cracking from

drying shrinkage.

WATER CEMENT RATIO - perhaps the most important parameter to

control is w/c ratio. It should be kept to the minimum

necessary to permit full hydration + adequate workability (as measured by a slump test). The theoretical minimum (~0.3)

ensures the full hydration reaction can occur + hence capillary pores are closed up + high interaction between cement grains

promotes strength. This in turn decreases permeability. Too much

water results in permeable, low strength concrete e.g. w/c ≈ 0.7.

LOW

4. (b) (i) Chloride induced corrosion

Chloride ions, typically from road salts or sea spray, (but also sometimes from old structures which had CaCl used to accelerate setting or whose aggregates or mix water were contaminated with salts) diffuse in towards the reinforcing steel. Once present at the bar surface in sufficient concentrations (corrosion typically initiated at $\text{Cl}^- > 0.4\%$ by weight of cement) then Cl^- ions act as a catalyst in the corrosion electrochemical cell leading to accelerated corrosion. Can get highly localized pitting corrosion in this process.

Carbonation

CO_2 from the atmosphere diffuses into the concrete and slowly generates a front of "carbonated" concrete with a higher pH due to the acidity of the carbonation process. When this carbonated front reaches the steel the passivating alkaline environment surrounding the bar is destroyed leading to corrosion. This form of corrosion often presents as general corrosion covering the entire surface of the bar.

Q4 b(ii) To detect corrosion

- (i) Half cell $> -350\text{mV} \Rightarrow$ high probability
- (ii) Visual inspection - observe rust (brown) staining
- spalling, particular along line of bar
- (iii) Resistivity - low value implies less resisting to corrosion cell current

Most techniques are indirect & only give indication of probability of corrosion.

Remedy for corrosion

- (i) Alternative r/f - stainless
- FRP
- Epoxy coated
- galvanized } expensive concrete repairs needed to cut out corroded steel. These options are best for new build structures.
- (ii) Cathodic protection - imposed electrical current suppresses corrosion process.
- (iii) Surface coatings - slow ingress of deleterious materials
- silane / epoxy membranes / bituminous
- (iv) Realkalisation - restore alkaline environment around bars
- (v) Desalination - extract chlorides from concrete.
- (vi) Patch repairs - often of limited effectiveness.

Q4(c) Whole life costing

OPTION 1

Repair £150,000 + 10 days @ £10K per day = £100K
 Repair every 20 years.
 Silane £20,000 + 2 days @ £10K/day = £20K
 Respray every 15 years.

OPTION 2

Repair £250,000 + 15 days @ £10K/day = £150K.
 Repair every 50 years.
 No silane

Discount rate $r = 3.5\%$

Life = 65 years.

$$\begin{aligned}
 NPV(\text{OPTION 1}) &= 250 + \frac{250}{(1.035)^{20}} + \frac{250}{(1.035)^{40}} + \frac{250}{(1.035)^{60}} \\
 &\quad + \frac{40}{(1.035)^{15}} + \frac{40}{(1.035)^{30}} + \frac{40}{(1.035)^{45}} + \frac{40}{(1.035)^{60}} \\
 &\hspace{15em} \text{(may not do last silane)} \\
 &= 250 \left(1 + \frac{1}{1.99} + \frac{1}{3.96} + \frac{1}{7.88} \right) + 40 \left(1 + \frac{1}{1.68} + \frac{1}{2.81} + \frac{1}{4.70} \right) \\
 &= 470.5 + 86.6 \\
 &= \underline{\underline{£557.1K}}
 \end{aligned}$$

$$\begin{aligned}
 NPV(\text{OPTION 2}) &= 400 + \frac{400}{(1.035)^{50}} = 400 \left(1 + \frac{1}{5.585} \right) \\
 &= \underline{\underline{£471.6K}}
 \end{aligned}$$

OPTION 2. CHEAPER. Adopt stainless steel on economic WLC basis.

4D7 Assessor's comments

Question 1 Axial and biaxial column behaviour

Parts (a) and (b) were generally well done however a few still struggled to calculate the neutral axis for bending about the M_x axis. A common mistake was to assume the distance from the surface to the centroid of the reinforcing bar was equal to the cover, rather than the cover plus half the bar radius. Many did not deduct the area taken up by the steel bars from the total area of concrete in compression, although this made only a small difference to the result. Part (c) on biaxial behaviour was less well done. Most recognised that assuming $\varepsilon_y / \varepsilon_{cu}$ was small implied that all the steel was yielded. In particular the derivation of the M_x component of the moments proved tricky for quite a few students, in many cases because of errors in determining the correct area and centroid of the compression zone of the column.

Question 2 Shear of RC Half-joint; Material properties

This was the least popular question but had by far the highest mean mark. This question had a somewhat open ended option to choose a strengthening solution for the shear reinforcement and, as a result, possibly attracted the more confident students. In most cases it was answered very well with sensible assumptions being made for the additional steel and the associated truss analogy.

Question 3 RC Beam deflection; Advanced Materials

Part (a) was quite straightforward for those who had understood the theory but again, quite a few students seemed to confuse the cracked second moment of area of the beam section, I_{cr} , with the uncracked value, I_{un} , with the latter being needed to derive the cracking moment required for the deflection calculation. With the benefit of hindsight, the question in part (a)(ii) should have stated that the distance from the *tension face* to the centroid was 208.1mm rather than from the *base of the section* to the centroid. As a result, this dimension was interpreted in different ways by various students. Both possible interpretations were accepted without penalty. Nevertheless this part of the question was well answered by a large majority of the candidates. Part (b) on advanced materials was perhaps less well answered than might be expected considering it was straight bookwork based on the lecture notes. As a result, the solutions were expected to be precise and cover both the potential advantages and also how they might be used in practice. Too often, one or the other of these two questions was omitted. Several confused High Strength/High Performance Concrete with Reactive Powder Concrete. Others discussed cement manufacture and types of cement rather than addressing the questions asked. Another common misconception was that fibre reinforcement might completely replace primary tension steel in structural sections rather than enhance the properties of the structural element, for example by reducing the potential for surface shrinkage cracking and reduce the need for temperature steel.

Question 4 Durability; Deterioration; Whole life costing

Part (a) was well answered by the vast majority of students although again, precise statements covering all the primary factors were required to obtain full marks. Part (b) was also answered well although some key points were overlooked in some answers. For example, it is important to recognise that chloride ions act as a catalyst and are not consumed in the corrosion process. Many failed to mention that most of the common methods used for detecting corrosion are in fact indirect methods which can only predict a probability that corrosion is present rather than actually measure the presence of corrosion directly. Part (c) was a standard whole life costing example. A number of candidates chose to select intervention periods for repair or silencing at intervals one year less than that specified. Although a relatively pedantic point, repair works specified to be undertaken at 20 year intervals means just that, after 20 years, not after 19 years as assumed by some. No marks were deducted from those who made this assumption.