CIVE 3206 WINTER 2013

ASSIGNMENT 2 SOLUTION

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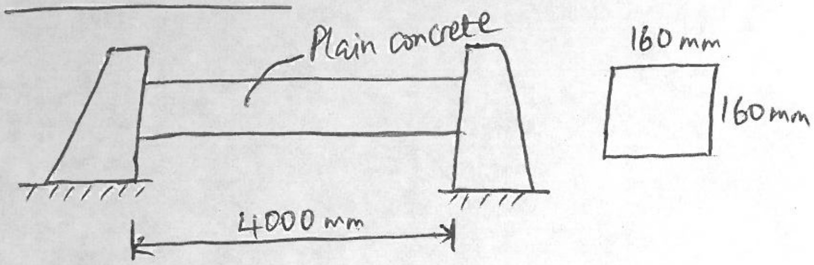
Question 1 (20 points)



$f'_c = 25\ MPa$

$\varepsilon'_c = -0.002$

$f_{cr} = 0.33\sqrt{f'_c}$

$E_{ct} = 5500\sqrt{f'_c}$

Ave. RH = 70%

(a) $\cancel{\varepsilon_{c,tot}}^{0} = \varepsilon_{cf} + \cancel{\varepsilon_{crp}}^{0} + \cancel{\varepsilon_{sh}}^{0} + \varepsilon_{c,th}$ ——— (1)

$\varepsilon_{c,tot} = 0 \rightarrow$ End restraints by rigid abutment

$\varepsilon_{crp} = 0 \rightarrow$ Short term load

$\varepsilon_{sh} = 0 \rightarrow$ Short term load

Compressive stress, $f_c = 7\ MPa$

$$f_c = f'_c\left[2\left(\frac{\varepsilon_{cf}}{\varepsilon'_c}\right) - \left(\frac{\varepsilon_{cf}}{\varepsilon'_c}\right)^2\right]$$ Hognestad Model of concrete in compression

$$7 = 25\left[2\left(\frac{\varepsilon_{cf}}{-0.002}\right) - \left(\frac{\varepsilon_{cf}}{-0.002}\right)^2\right]$$

$$0.28 = -1000\,\varepsilon_{cf} - 250{,}000\,\varepsilon_{cf}^2$$

$$250{,}000\,\varepsilon_{cf}^2 + 1000\,\varepsilon_{cf} + 0.28 = 0$$

$$\varepsilon_{cf} = -0.303\times10^{-3}$$ ie. least strain corresponding to stresss

from eqn (1) above, $\varepsilon_{c,th} = -\varepsilon_{cf}$

$$\Delta T\,\alpha_c = -\varepsilon_{cf}$$

$\alpha_c = 6\times10^{-6}\ °C^{-1}$ for limestone concrete

$$\therefore\ (-6\times10^{-6})\,\Delta T = -0.303\times10^{-3}$$

$$\Delta T = \underline{\underline{50.5\,°C}}$$

(b) $f_{cr} = 0.33\sqrt{25} = 1.65$ MPa

$E_{ct} = 5500\sqrt{25} = 27,500$ MPa

$$\varepsilon_{cf} = \frac{f_{cr}}{E_{ct}} = \frac{1.65}{27,500} = 0.06\times10^{-3}$$

$$\cancel{\varepsilon_{c,tot}}^{\,0} = \varepsilon_{cf} + \cancel{\varepsilon_{crp}}^{\,0} + \cancel{\varepsilon_{sh}}^{\,0} + \varepsilon_{c,th}$$

$$\Rightarrow \quad \varepsilon_{c,th} = -\varepsilon_{cf}$$

$$\alpha_c \Delta T = -0.06\times10^{-3}$$

$$6\times10^{-6}\,\Delta T = -0.06\times10^{-3}$$

$$\Delta T = \underline{\underline{-10^\circ C}}$$

(c) $\Delta T = -50^\circ C$

$$\varepsilon_{c,tot} = \cancel{\varepsilon_{cf}}^{\,\text{cracked}} + \cancel{\varepsilon_{crp}}^{\,0} + \cancel{\varepsilon_{sh}}^{\,0} + \varepsilon_{c,th}$$

$$\varepsilon_{c,tot} = \varepsilon_{c,th}$$

$$\frac{\Delta}{l_o} = \alpha_c \Delta T$$

$$\Delta = \alpha_c \Delta T\, l_o$$

$$= 6\times10^{-6}(-50)(4000)$$

$$\Delta = \underline{\underline{-1.2\text{ mm}}}$$

(d) $\varepsilon_{sh} = -\varepsilon_{cf} = -0.06\times10^{-3}$

$$\therefore -0.06\times10^{-3} = -k_s k_h \left(\frac{t}{35+t}\times0.51\times10^{-3}\right)$$

$$0.06\times10^{-3} = (1.0)(1.0)\left(\frac{t}{35+t}\times0.51\times10^{-3}\right)$$

$$0.118 = \frac{t}{35+t}$$

$$t = \underline{\underline{4.67\text{ days}}}$$

$$\frac{\text{Volume}}{\text{Surface Area}} = \frac{160(160)(4000)}{4\times(160\times4000)} = 40$$

$\therefore k_s = 1.0$

$k_h \rightarrow$ Ave. H = 70% $\Rightarrow k_h = 1.0$

(e) $\varepsilon_{sh} = -0.04 \times 10^{-3}$

$\varepsilon_{c,tot} = \cancel{\varepsilon_{cf}}^{\,0} + \cancel{\varepsilon_{creep}}^{\,0} + \varepsilon_{sh} + \cancel{\varepsilon_{c,th}}^{\,0}$

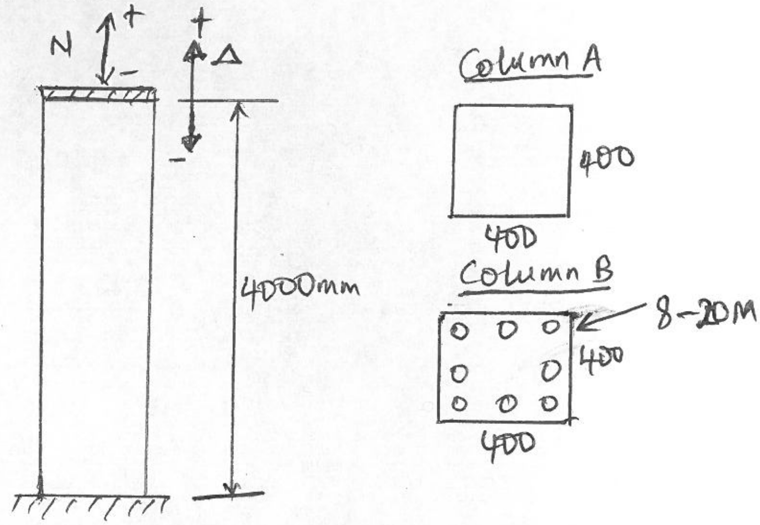
$\varepsilon_{c,tot} = \varepsilon_{sh} = -0.04 \times 10^{-3}$

$\Delta = \varepsilon_{c,tot} \cdot l_0$

$= -0.04 \times 10^{-3} \times 4000$

$\Delta = -1.6\,mm$

QUESTION 2 (80 points)



$f_c' = 35$ MPa

$\varepsilon_c' = -0.002$

$f_{cr} = 0.33\sqrt{f_c'}$

$E_{ct} = 5500\sqrt{f_c'}$

$f_y = 400$ MPa

$E_s = 200{,}000$ MPa

Avg. R.H = 70%

Short Term (40 Points)

No creep, Shrinkage or Thermal Effects

$\Rightarrow \varepsilon_{creep} = 0$, $\varepsilon_{sh} = 0$, $\varepsilon_{c,th}$ or $\varepsilon_{s,th} = 0$

Column A: No Reinforcement

$\therefore \varepsilon_{c,tot} = \varepsilon_{c,f} + \cancelto{0}{\varepsilon_{crp}} + \cancelto{0}{\varepsilon_{sh}} + \cancelto{0}{\varepsilon_{c,th}}$

$\varepsilon_{c,f} = \varepsilon_{c,tot}$ Concrete section resists total strain

Column B: Concrete + Reinforcement

$\varepsilon_{c,tot} = \varepsilon_{c,f} + \cancelto{0}{\varepsilon_{crp}} + \cancelto{0}{\varepsilon_{sh}} + \cancelto{0}{\varepsilon_{c,th}}$

$\varepsilon_{c,f} = \varepsilon_{c,tot}$

$\varepsilon_{s,tot} = \varepsilon_{s,f} + \cancelto{0}{\varepsilon_{s,th}}$

$\varepsilon_{s,f} = \varepsilon_{s,tot}$

Due to perfect bond between concrete and steel,

$\varepsilon_{s,tot} = \varepsilon_{c,tot} = \varepsilon_{tot}$ and

$\varepsilon_{s,f} = \varepsilon_{c,f}$

Stresses

Concrete in Compression (Hognestad Parabola):

$$f_c = -f_c'\left[2\left(\frac{\varepsilon_{cf}}{\varepsilon_c'}\right) - \left(\frac{\varepsilon_{cf}}{\varepsilon_c'}\right)^2\right]$$

$f_c = 0$ if $\varepsilon_{cf} > 2\varepsilon_c'$ (Ultimate Point)

Concrete in Tension:

$f_c = \varepsilon_{cf} \cdot E_{ct}$ if $\varepsilon_{c,f} \leq \varepsilon_{cr}$

$f_c = 0$ if $\varepsilon_{c,f} > \varepsilon_{cr}$

Steel:

$$\underset{\text{compression}}{-f_y\,(400\,\text{MPa})} \leq f_s = E_s \cdot \varepsilon_{s,f} \leq \underset{\text{Tension}}{f_y\,(400\,\text{MPa})}$$

Axial Load

$N = N_c = A_c f_c \longrightarrow$ Column A

$N = N_c + N_s = A_c f_c + A_s f_s \longrightarrow$ Column B

$\phi\,(20M) = 19.5\,\text{mm}$ 8–20M Area, $A_s = 8 \times \frac{\pi\,(19.5)^2}{4} \approx 2400\,\text{mm}^2$

$A_c = (400 \times 400) - A_s = 157{,}600\,\text{mm}^2 \longrightarrow$ Column B

Sample Calculation (Compression)

Choose $\varepsilon_{c,tot} = -1 \times 10^{-3}$

$\Delta = \varepsilon_{c,tot} \cdot l_0 = -4\,\text{mm}$

Concrete

$\varepsilon_{c,f} = \varepsilon_{c,tot} = \varepsilon_{tot} = -1 \times 10^{-3}$

$$f_c = -35\left[2\left(\frac{-1\times10^{-3}}{-2\times10^{-3}}\right) - \left(\frac{-1\times10^{-3}}{-2\times10^{-3}}\right)^2\right] = -26.25\,\text{MPa}$$

$$F_c = A_c f_c = 157{,}600 \times (-26.25) = -4{,}137\,kN$$

Steel

$$\varepsilon_{s,f} = \varepsilon_{c,tot} = \varepsilon_{,tot} = -1 \times 10^{-3}$$

Compare with $\varepsilon_{s,y} = \dfrac{f_y}{E_s} = \dfrac{400}{2\times10^5} = 0.002$ $\Big\}$ $0.001 < 0.002$ not yielded yet

$$f_s = E_s \cdot \varepsilon_{s,f} = 2\times10^5 \times (-1\times10^{-3}) = -200\,MPa$$

$$F_s = A_s f_s = 2400\,(-200) = -480\,kN$$

For Column A:

$$N = F_c = A_c f_c = 400^2 \times -26.25 = -4200\,kN$$

For Column B:

$$N = F_c + F_s = -4137 + (-480) = -4617\,kN$$

Sample Calculation (Tension)

$$\varepsilon_{cr} = \frac{f_{cr}}{E_{ct}} = \frac{0.33\sqrt{f_c'}}{5500\sqrt{f_c'}} = 0.06\times10^{-3}$$

(1) Just a Little before crack;

Concrete: $\varepsilon_{c,tot} = +0.06\times10^{-3}$

$$\varepsilon_{cf} = \varepsilon_{c,tot} = +0.06\times10^{-3}$$

$$f_c = E_{ct} \cdot \varepsilon_{cf} = 5500 \times \sqrt{35} \times 0.06\times10^{-3} = 1.95\,MPa$$

$$F_c = A_c f_c = 400^2 \times 1.95 = 312\,kN \longrightarrow \text{Column A}$$

$$F_c = A_c f_c = 157{,}600 \times 1.95 = 307.32\,kN \longrightarrow \text{Column B}$$

steel:

$$\varepsilon_{sf} = \varepsilon_{s,tot} = 0.06\times10^{-3}$$

$$f_s = E_s \cdot \varepsilon_{sf} = 2\times10^5 \times 0.06\times10^{-3} = 12\,MPa$$

$$F_s = A_s f_s = 2400 \times 12 = 28.8\,kN$$

$\therefore N = 312\text{ kN} \longrightarrow$ column A

$N = F_c + F_s$

$= 307.32 + 28.8$

$N = 336\text{ kN} \longrightarrow$ column B

(2) Just a little after crack:

$\varepsilon_{cf} = \varepsilon_{c,tot} > +0.06 \times 10^{-3}\ (\varepsilon_{cr})$

Hence $f_c = 0$ since concrete cannot resist tensile forces

$\therefore N = 0 \longrightarrow$ column A

$N = (\varepsilon_{sf} \cdot E_s)\, A_s \longrightarrow$ column B

NOTE;

- Concrete fails/crushes when its ultimate strain is reached ie. $\varepsilon_c' = -0.002$ and its maximum compressive strength is also achieved. The maximum compressive load for Column A is -5600 kN.

  In the case of column B where steel reinforcement are added, the steel yields at the strain at which concrete fails ie. $\varepsilon_y = -0.002$.
  It is realised that the inclusion of reinforcement increases the compressive load capacity of column B ~~to~~ -6476 kN.

- Concrete cracks when $\varepsilon_{cf} \cong 0.00006$ (crack strain, ε_{cr}) and the maximum tensile load is reached for Column A ie. 312 kN
  However column B with reinforcement is able to resist a great amount of tensile load up to 960 kN even

after the concrete cracks.
Beyond the crack strain, the tensile capacity of Column B is controlled by the steel and its maximum is obtained when the steel finally yields at $\varepsilon_y = 0.002$.

The observations from above indicate that both the compressive and tensile capacity of a column are increased significantly due to the presence of reinforcement.

Long Term (40 points)

No Thermal effects : $\varepsilon_{c,th}, \varepsilon_{s,th} = 0$

Shrinkage and Creep effects 18 years after casting

Shrinkage → ε_{sh}

Creep → $\phi(t, t_i)$ → creep coefficient

$$\varepsilon_{c,tot} = \varepsilon_{c,f}(t, t_i) + \varepsilon_{sh}$$

$$\Rightarrow \varepsilon_{cf}(t, t_i) = \varepsilon_{c,tot} - \varepsilon_{sh}$$

$$\varepsilon_{s,tot} = \varepsilon_{sf}$$

$$\Rightarrow \varepsilon_{sf} = \varepsilon_{s,tot}$$

Due to perfect bond between concrete and steel,

$$\varepsilon_{c,tot} = \varepsilon_{s,tot} = \varepsilon_{tot}$$

$$\Delta = \varepsilon_{tot} \cdot L_0$$

Creep

$$\phi(t, t_i) = 3.5\, K_c K_f \left(1.58 - \frac{H}{120}\right) t_i^{-0.118} \times \frac{(t - t_i)^{0.6}}{10 + (t - t_i)^{0.6}}$$

Day of Casting $\xrightarrow{\text{1 week}}$ Formwork removed $\xrightarrow{\text{7 weeks}}$ Load Applied

t_i = time at which load is applied after casting

t_i = 8 weeks × 7 = 56 days

$(t - t_i)$ = time under load = 18 yrs − t_i = 18 × 365 − 56 = 6514 days

H = 70 (Avg. R.H = 70%)

$$\frac{\text{Volume}}{\text{Surface Area}} = \frac{V}{SA} = \frac{400^2 \times 4000}{4 \times (400 \times 4000)} = 100\,mm$$

$$\left.\begin{array}{l} \frac{V}{SA} = 100\,mm \\ (t - t_i) = 6514 \text{ days} \end{array}\right\} K_c = 0.78$$

$$K_f = \frac{1}{0.67 + (f_c'/64)} = \frac{1}{0.67 + 35/64} = 0.82$$

$$\phi(t, t_i) = 3.5 \times 0.78 \times 0.82 \left(1.58 - \frac{70}{120}\right)(56)^{-0.118} \times \frac{(6514)^{0.6}}{10 + (6514)^{0.6}}$$

$$\phi(t, t_i) = 1.303$$

$$\varepsilon_{c,eff}' = \varepsilon_c'(1 + \phi(t,t_i))$$
$$= -0.002(1 + 1.303)$$
$$\varepsilon_{c,eff}' = -0.00461$$

$$E_{c,eff} = \frac{E_{ct}}{(1 + \phi(t,t_i))}$$
$$= \frac{5500\sqrt{35}}{1 + 1.303}$$
$$E_{c,eff} = 14128.72$$

Shrinkage

time of drying, $t_{drying} = 18 \times 365 - 7 = 6563$ days

$\left.\begin{array}{l} \frac{V}{SA} = 100mm \\ t_{drying} = 6563 \text{ days} \end{array}\right\} K_s = 0.75$ $\qquad K_h = 1.0$ (for Avg. RH = 70%)

$$\varepsilon_{sh} = -K_s \cdot K_h \left(\frac{t_{drying}}{35 + t_{drying}}\right) \times 0.51 \times 10^{-3}$$

$$\varepsilon_{sh} = -0.75 \times 1.0 \times \left(\frac{6563}{35 + 6563}\right) \times 0.51 \times 10^{-3} = -0.38 \times 10^{-3}$$

Crack strain of concrete:

$$\varepsilon_{cr} = \frac{f_{cr}}{E_{c,eff}} = \frac{0.33\sqrt{35}}{14128.72} = 0.138 \times 10^{-3}$$

Stresses

Concrete in compression (Hognestad Parabola):

$$f_c = -f_c'\left[2\left(\frac{\varepsilon_{cf}(t,t_i)}{\varepsilon_{c,eff}'}\right) - \left(\frac{\varepsilon_{cf}(t,t_i)}{\varepsilon_{c,eff}'}\right)^2\right]$$

$$f_c = 0 \quad \text{if} \quad \varepsilon_{cf}(t,t_i) > 2\,\varepsilon_{c,eff}'$$

Concrete in Tension:

$$f_c = \varepsilon_{cf(t,t_i)} \cdot E_{c,eff} \qquad \text{if} \qquad \varepsilon_{cf}(t,t_i) \leq \varepsilon_{cr}$$

$$f_c = 0 \qquad \text{if} \qquad \varepsilon_{cf}(t,t_i) > \varepsilon_{cr}$$

Steel:

$$-f_y \leq f_s = E_s \cdot \varepsilon_{sf} \leq +f_y$$

Sample Calculation (Compression)

Choose $\varepsilon_{tot} = -1 \times 10^{-3}$

$$\Delta = \varepsilon_{tot} \cdot l_0 = -4\,mm$$

Concrete:

$$\varepsilon_{c,tot} = \varepsilon_{tot} = -1 \times 10^{-3}$$

$$\varepsilon_{cf}(t,t_i) = -1 \times 10^{-3} - (-0.38 \times 10^{-3}) = -0.62 \times 10^{-3}$$

$$f_c = -35 \left[2 \left(\frac{-0.62 \times 10^{-3}}{-0.00461} \right) - \left(\frac{-0.62 \times 10^{-3}}{-0.00461} \right)^2 \right] = -8.78\,MPa$$

Steel

$$\varepsilon_{s,tot} = \varepsilon_{tot} = -1 \times 10^{-3}$$

$$\varepsilon_{sf} = \varepsilon_{s,tot} = -1 \times 10^{-3} < \varepsilon_y = -2 \times 10^{-3} \text{ (not yielded yet)}$$

$$f_s = \varepsilon_{sf} \cdot E_s = -1 \times 10^{-3} \times (2 \times 10^5) = -200\,MPa$$

For Column A:

$$N = F_c = A_c f_c = 400^2 \times -8.78 = -1405\,kN$$

For Column B:

$$N = F_c + F_s = A_c f_c + A_s f_s$$

$$= 157{,}600(-8.78) + 2400(-200)$$

$$N = -1863.7\,kN$$

Sample Calculation (Tension)

Choose $\varepsilon_{tot} = -0.32 \times 10^{-3}$

$\Delta = \varepsilon_{tot} \cdot L_0 = -1.28\,mm$

Concrete

$\varepsilon_{c,tot} = \varepsilon_{tot} = -0.32 \times 10^{-3}$

$\varepsilon_{cf}(t, t_i) = -0.32 \times 10^{-3} - (-0.38 \times 10^{-3}) = +0.06 \times 10^{-3} < \varepsilon_{cr}$

$\therefore \; f_c = \varepsilon_{cf}(t, t_i) \cdot E_{c,eff}$

$= 0.06 \times 10^{-3} \times 14128.72$

$f_c = 0.85\,MPa$

Steel

$\varepsilon_{s,tot} = \varepsilon_{tot} = -0.32 \times 10^{-3}$

$\varepsilon_{sf} = \varepsilon_{s,tot} = -0.32 \times 10^{-3} < -2 \times 10^{-3}$ (not yielded yet)

$f_s = \varepsilon_{sf} \cdot E_s = -0.32 \times 10^{-3} (2 \times 10^{5}) = -64\,MPa$

For column A:

$N = A_c f_c = 400^2 \times 0.85 = 136\,kN$

For Column B:

$N = A_c f_c + A_s f_s$

$= 157{,}600(0.85) + 2400(-64)$

$N = -19.6\,kN$

NOTE:

- The compressive and tensile load capacity of both columns remain the same as the short term case ie. -6476 kN and 960 kN for column B respectively and $-5{,}600$ kN and 312 kN for column A respectively.

- The Maximum compressive Load for both columns is reached at a higher compressive strain ($\varepsilon_{cf}(t,t_i) = -0.00461$) as compared to the short-term case which occurs at $\varepsilon_{cf} = -0.002$.
  The concrete crushes at this point as its ultimate compressive strength is reached ($f_c' = -35$ MPa)
  It is evident that both columns are able to sustain much deformation in the long term case as compared to the short term case. as the graph shows.

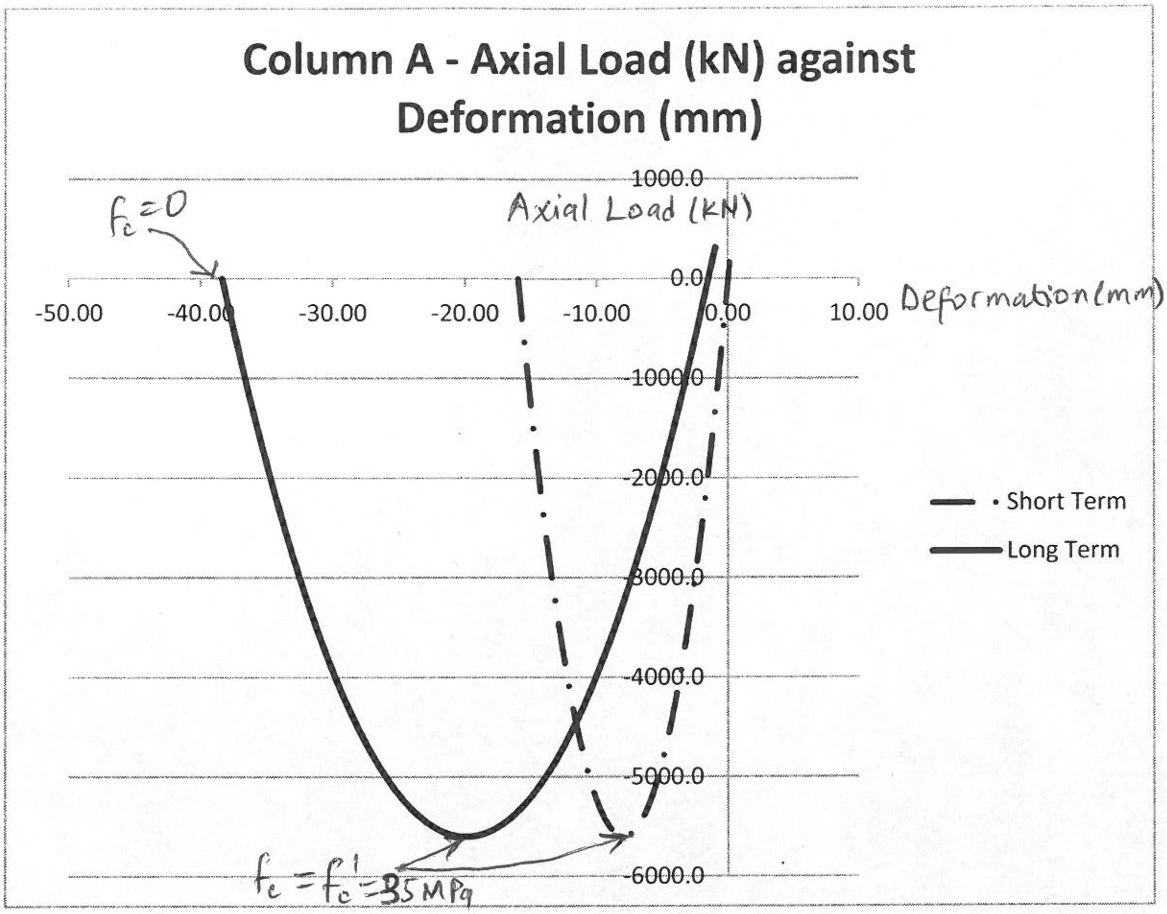
- Cracking of the concrete occurs at a higher tensile strain ($\varepsilon_{cf}(t,t_i) = 0.000138$) as compared to the short term case at $\varepsilon_{cf} = 0.00006$.
  Also the maximum tensile load for Column B occurs at a higher strain ($\varepsilon_{cf}(t,t_i) = 0.00238$) as compared to the short-term case at $\varepsilon_{cf} = 0.002$.
  This is reflected in the graph as Column B sustains a higher deformation in tension for the long term as compared to the short term.

COLUMN A (Short Term)

Strain ($\varepsilon c,tot$)	fc (MPa)	N (kN)	Δ (mm)	Comments
-0.00400	0.00	0.0	-16.00	
-0.00398	-0.70	-111.4	-15.92	
-0.00204	-34.99	-5597.8	-8.16	
-0.00202	-35.00	-5599.4	-8.08	
-0.00200	-35.00	-5600.0	-8.00	Max. Comp. Load and Concrete Crushes
-0.00198	-35.00	-5599.4	-7.92	
-0.00004	-1.39	-221.8	-0.16	
-0.00002	-0.70	-111.4	-0.08	
0.00000	0.00	0.0	0.00	
0.00002	0.65	104.1	0.08	
0.00004	1.30	208.2	0.16	
0.00006	1.95	312.4	0.24	Max. Tensile Load and Concrete Cracks

COLUMN A (Long Term)

Strain ($\varepsilon c,tot$)	Strain $\varepsilon cf(t,ti)$	fc (MPa)	N (kN)	Δ (mm)	Comments
-0.00960	-0.00922	0.00	0.0	-38.40	
-0.00508	-0.00470	-34.99	-5597.9	-20.32	
-0.00504	-0.00466	-35.00	-5599.3	-20.16	
-0.00499	-0.00461	-35.00	-5600.0	-19.96	Max. Comp. Load and Concrete Crushes
-0.00496	-0.00458	-35.00	-5599.8	-19.84	
-0.00048	-0.00010	-1.50	-240.3	-1.92	
-0.00044	-0.00006	-0.91	-144.8	-1.76	
-0.00040	-0.00002	-0.30	-48.5	-1.60	
-0.00036	0.00002	0.28	45.2	-1.44	
-0.00032	0.00006	0.85	135.6	-1.28	
-0.00028	0.00010	1.41	226.1	-1.12	
-0.000242	0.000138	1.95	312.0	-0.97	Max. Tensile Load and Concrete Cracks


Column A - Axial Load (kN) against Deformation (mm)
1000.0
0.0
-1000.0
-2000.0
-3000.0
-4000.0
-5000.0
-6000.0
-50.00
-40.00
-30.00
-20.00
-10.00
0.00
10.00
Axial Load (kN)
Deformation (mm)
$f_c = 0$
$f_c = f_c' = 35$ MPa
Short Term
Long Term

COLUMN B (Short Term)

Strain ($\varepsilon_{c,tot}$)	Strain ($\varepsilon_{s,tot}$)	f_c (MPa)	f_s (MPa)	N (kN)	Δ (mm)	Comments
-0.00400	-0.00400	0.00	-400.00	-960.00	-16.00	
-0.00398	-0.00398	-0.70	-400.00	-1069.77	-15.92	
-0.00396	-0.00396	-1.39	-400.00	-1178.43	-15.84	
-0.00202	-0.00202	-35.00	-400.00	-6475.45	-8.08	
-0.00200	-0.00200	-35.00	-400.00	-6476.00	-8.00	Max. Compressive load. Concrete crushes and steel yields in compression
-0.00198	-0.00198	-35.00	-396.00	-6465.85	-7.92	
-0.00196	-0.00196	-34.99	-392.00	-6454.59	-7.84	
-0.00002	-0.00002	-0.70	-4.00	-119.37	-0.08	
0.00000	0.00000	0.00	0.00	0.00	0.00	
0.00002	0.00002	0.65	4.00	112.16	0.08	
0.00004	0.00004	1.30	8.00	224.32	0.16	
0.00006	0.00006	1.95	12.00	336.48	0.24	Just Before cracking in concrete
0.00008	0.00008	0.00	16.00	38.40	0.32	Just After cracking in concrete
0.00010	0.00010	0.00	20.00	48.00	0.40	
0.00194	0.00194	0.00	388.00	931.20	7.76	
0.00196	0.00196	0.00	392.00	940.80	7.84	
0.00198	0.00198	0.00	396.00	950.40	7.92	
0.00200	0.00200	0.00	400.00	960.00	8.00	Maximum tensile load and Steel yields in tension

COLUMN B (Long Term)

Strain ($\varepsilon_{c,tot}$)	Strain $\varepsilon_{cf(t,ti)}$	Strain (ε_{sf})	fc (MPa)	fs (MPa)	N (kN)	Δ (mm)	Comments
-0.00960	-0.00922	-0.00960	0.00	-400.00	-960.00	-38.40	
-0.00956	-0.00918	-0.00956	-0.60	-400.00	-1055.31	-38.24	
-0.00504	-0.00466	-0.00504	-35.00	-400.00	-6475.35	-20.16	
-0.00499	-0.00461	-0.00499	-35.00	-400.00	-6476.00	-19.96	Max. compressive load and concrete crushes
-0.00496	-0.00458	-0.00496	-35.00	-400.00	-6475.77	-19.84	
-0.00492	-0.00454	-0.00492	-34.99	-400.00	-6474.73	-19.68	
-0.00204	-0.00166	-0.00204	-20.67	-400.00	-4217.26	-8.16	
-0.00200	-0.00162	-0.00200	-20.28	-400.00	-4155.59	-8.00	Steel yields in compression
-0.00196	-0.00158	-0.00196	-19.88	-392.00	-4073.89	-7.84	
-0.00036	0.00002	-0.00036	0.28	-72.00	-128.27	-1.44	
-0.00032	0.00006	-0.00032	0.85	-64.00	-20.00	-1.28	
-0.00028	0.00010	-0.00028	1.41	-56.00	88.27	-1.12	
-0.000242	0.000138	-0.000242	1.95	-48.40	191.12	-0.97	Just Before cracking in concrete
-0.00020	0.00018	-0.00020	0.00	-40.40	-96.96	-0.81	Just After cracking in concrete
-0.00016	0.00022	-0.00016	0.00	-32.40	-77.76	-0.65	
0.00196	0.00234	0.00196	0.00	391.60	939.84	7.83	
0.00200	0.00238	0.00200	0.00	400.00	960.00	8.00	Maximum tensile load and Steel yields in tension

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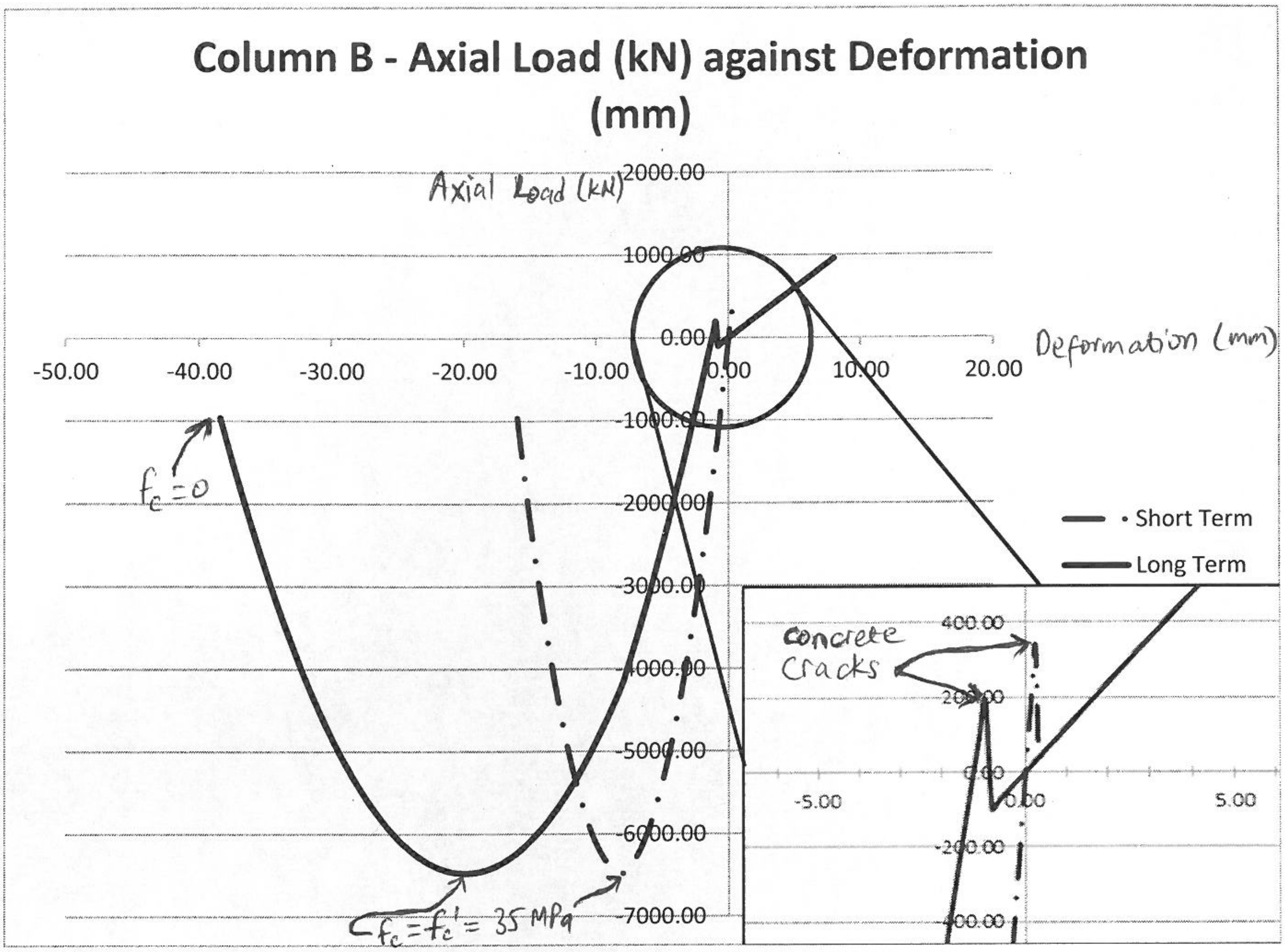

Q 1 — 20 points

Q 2 — 80 points

Short Term — 35 pts: Column A — 15 pts, Column B — 20 pts

Long Term — 35 pts: Column A — 15 pts, Column B — 20 pts

Discussion — 10 pts

Total = 100