XI'AN JIAOTONG-LIVERPOOL UNIVERSITY
西交利物浦大学

COURSEWORK SUBMISSION COVER SHEET

Name	Xu (Surname)	Minghong (Other Names)
Student Number	1929836	
Programme	Mechatronics and Robotic Systems	
Module Title	Solids and Structures	
Module Code	CEN103	
Assignment Title	Coursework 1	
Submission Deadline	3 May 2021, 5PM	
Module Leader	Charles Kwet Shin Loo Chin May	

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Signature ......徐铭鸿...... Date ......4 May 2021......

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Feedback on the strength of the work

Feedback on the weakness that needs to be improved

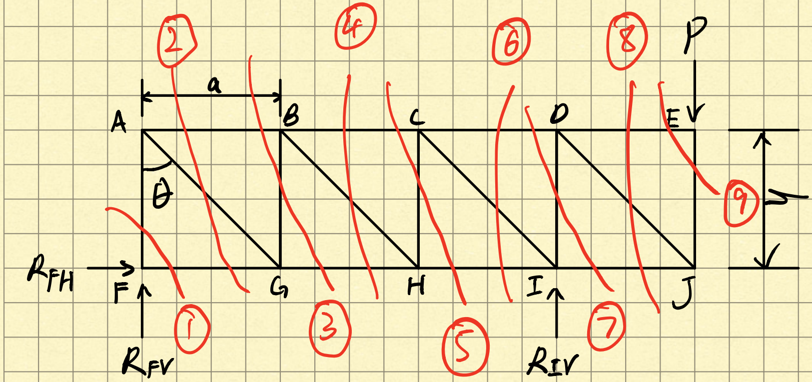
1st Marker___________________________ Date__________ Mark_________

2nd Marker___________________________ Date_________ Mark_________
(if applicable)

Students: *Please start your assignment on the next page.*

Part A

Q1



Solving reactions

+ve

$\circlearrowleft$ +ve

$$\cos\theta = \frac{h}{\sqrt{a^2+h^2}} \qquad \tan\theta = \frac{a}{h}$$

$\sum F_V = 0; \quad R_{FV} + R_{IV} - P = 0$ —— ①

$\sum F_H = 0; \quad R_{FH} = 0$

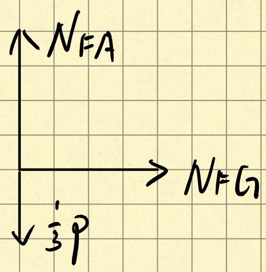
$\sum M_F = 0; \quad P \times 4a - R_{IV} \times 3a = 0$

$R_{IV} = \frac{4}{3}P$ —— ②

Sub ② into ①

$R_{FV} = -\frac{1}{3}P$

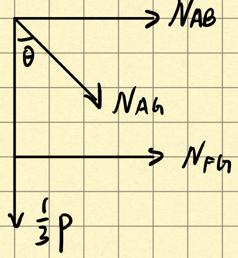
Section ①



$\sum F_V = 0; \quad N_{FA} = \frac{1}{3}P$

$\sum F_H = 0; \quad N_{FG} = 0$

Section ②



$$\sum F_V = 0; \quad -N_{AG}\cos\theta - \frac{1}{3}P = 0$$

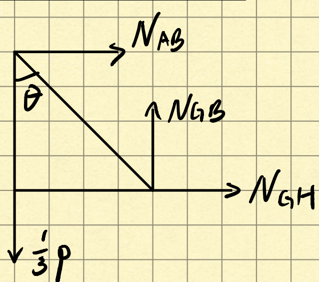
$$N_{AG} = -\frac{P}{3\cos\theta} \quad \text{———} ③$$

$$\sum F_H = 0; \quad N_{AB} + N_{AG}\sin\theta = 0 \quad \text{———} ④$$

Sub ③ into ④

$$N_{AB} = \frac{1}{3}P\tan\theta$$

Section ③



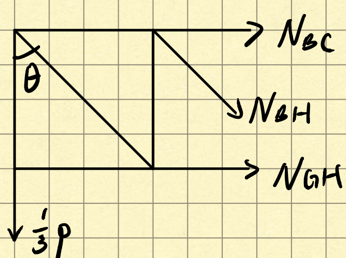
$$\sum F_V = 0; \quad N_{GB} - \frac{1}{3}P = 0$$

$$N_{GB} = \frac{1}{3}P$$

$$\sum F_H = 0; \quad N_{GH} + N_{AB} = 0$$

$$N_{GH} = -\frac{1}{3}P\tan\theta$$

Section ④



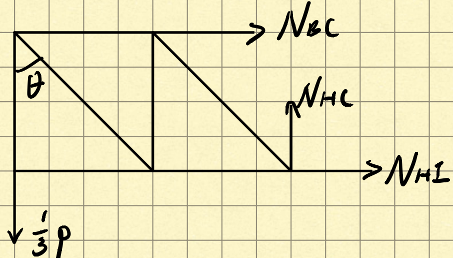
$$\sum F_V = 0; \quad -N_{BH}\cos\theta - \frac{1}{3}P = 0$$

$$N_{BH} = -\frac{P}{3\cos\theta}$$

$$\sum F_H = 0; \quad N_{BC} + N_{GH} + N_{BH}\sin\theta = 0$$

$$N_{BC} = \frac{2}{3}P\tan\theta$$

Section ⑤



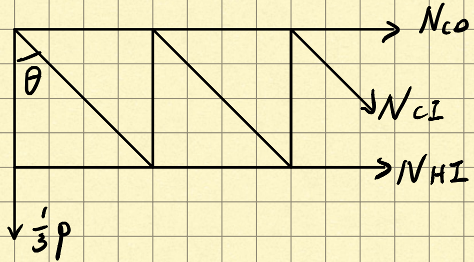
$$\sum F_V = 0; \quad N_{HC} - \frac{1}{3}P = 0$$

$$N_{HC} = \frac{1}{3}P$$

$$\sum F_H = 0; \quad N_{BC} + N_{HI} = 0$$

$$N_{HI} = -\frac{2}{3}P\tan\theta$$

Section ⑥



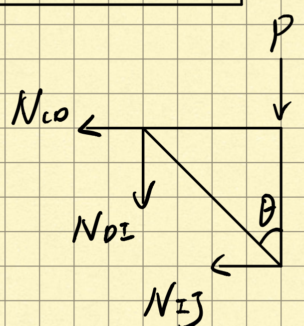
$$\Sigma F_V = 0; \quad -N_{CI}\cos\theta - \frac{1}{3}P = 0$$

$$N_{CI} = -\frac{P}{3\cos\theta}$$

$$\Sigma F_H = 0; \quad N_{CD} + N_{HI} + N_{CI}\cos\theta = 0$$

$$N_{CD} = P\tan\theta$$

Section ⑦



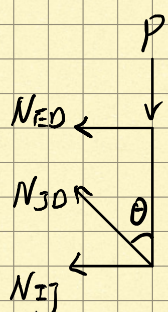
$$\Sigma F_V = 0; \quad -N_{DI} - P = 0$$

$$N_{DI} = -P$$

$$\Sigma F_H = 0; \quad -N_{IJ} - N_{CD} = 0$$

$$N_{IJ} = -P\tan\theta$$

Section ⑧



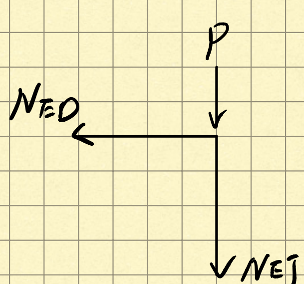
$$\Sigma F_V = 0; \quad N_{JD}\cos\theta - P = 0$$

$$N_{JD} = \frac{P}{\cos\theta}$$

$$\Sigma F_H = 0; \quad -N_{ED} - N_{IJ} - N_{JD}\sin\theta = 0$$

$$N_{ED} = 0$$

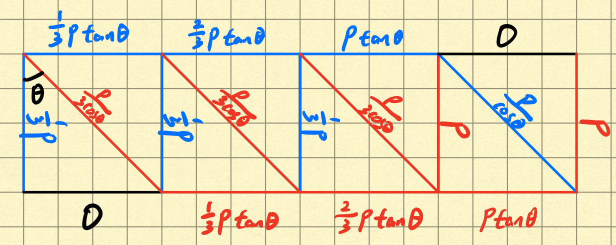
Section ⑨



$$\Sigma F_V = 0; \quad -N_{EJ} - P = 0$$

$$N_{EJ} = -P$$

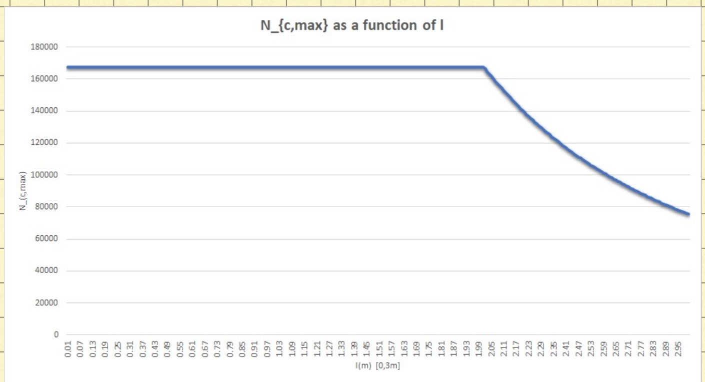
Q2



Q3

	members	N_t_max	N_c_max
0	AB	167580	167580.00
1	BC	167580	167580.00
2	CD	167580	167580.00
3	DE	167580	167580.00
4	FG	167580	167580.00
5	GH	167580	167580.00
6	HI	167580	167580.00
7	IJ	167580	167580.00
8	AF	167580	167580.00
9	BG	167580	167580.00
10	CH	167580	167580.00
11	DI	167580	167580.00
12	EJ	167580	167580.00
13	AG	167580	84940.28
14	BH	167580	84940.28
15	CI	167580	84940.28
16	DJ	167580	84940.28

Q4



Q5

	members	force type	coefficient of P	P (N)
0	AB	T	0.333333	4000.000000
1	BC	T	0.666667	8000.000000
2	CD	T	1.000000	12000.000000
3	DE	N	0.000000	0.000000
4	FG	N	0.000000	0.000000
5	GH	C	0.333333	4000.000000
6	HI	C	0.666667	8000.000000
7	IJ	C	1.000000	12000.000000
8	AF	T	0.333333	4000.000000
9	BG	T	0.333333	4000.000000
10	CH	T	0.333333	4000.000000
11	DI	C	1.000000	12000.000000
12	EJ	C	1.000000	12000.000000
13	AG	C	0.471405	5656.854249
14	BH	C	0.471405	5656.854249
15	CI	C	0.471405	5656.854249
16	DJ	T	1.414214	16970.562748

For software simulation, see Appendix Q5

Q6

maximum load = 118496.95 N

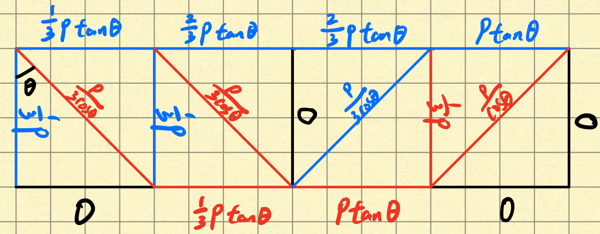
For solution, see Appendix Python solution

Q7

maximum load = 60061.85 N

For solution, see Appendix Python solution

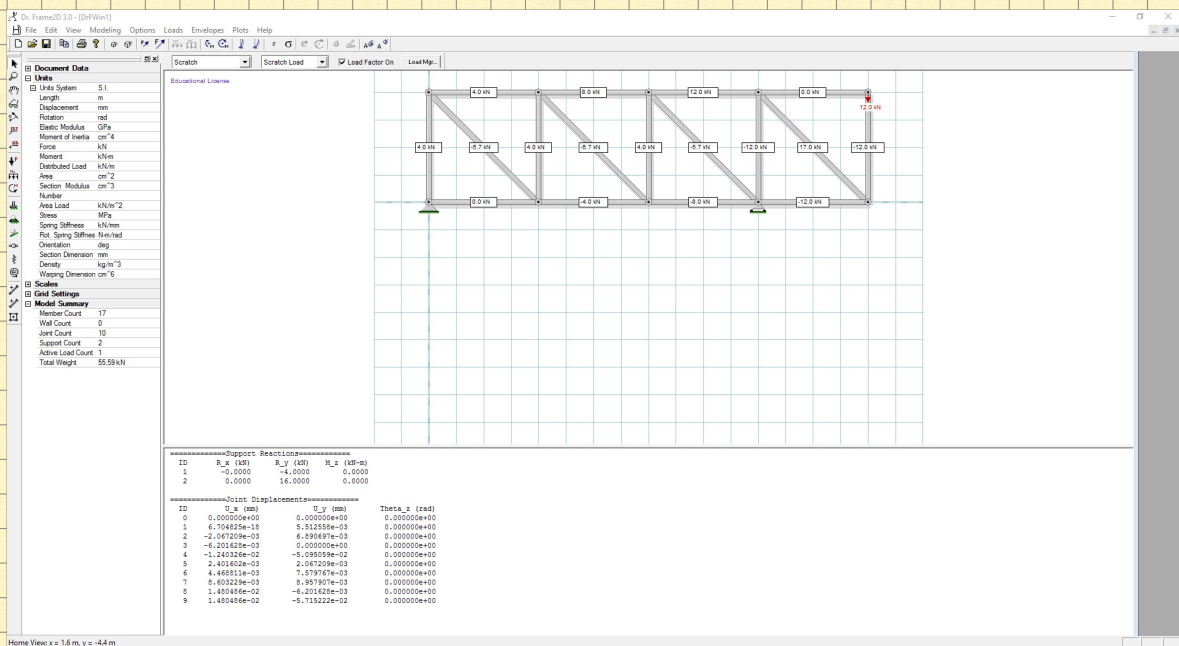
Q8



Compare to the first truss, this has more members that contribute nothing to the whole structure; therefore, this truss has lower maximum load than the first one.

Appendix

Q5

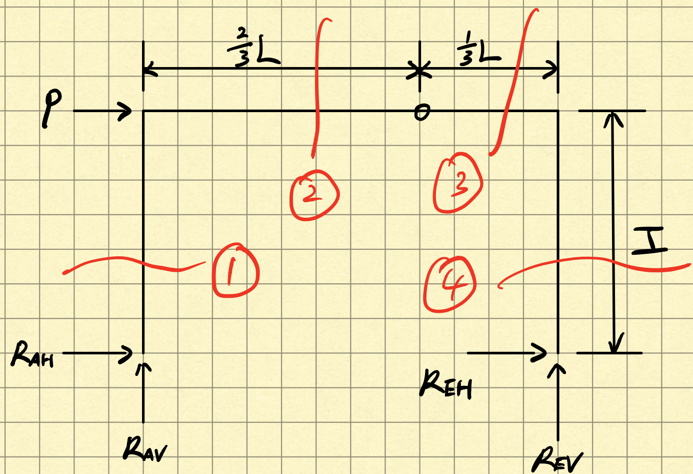


Python Solution

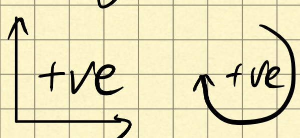
```python
import pandas as pd
import math


class Q3:

    data = pd.DataFrame({
        "members": ["AB", "BC", "CD", "DE", "FG", "GH", "HI", "IJ", "AF", "BG", "CH", "DI", "EJ", "AG", "BH", "CI",
                    "DJ"],
        "N_t_max": [167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580,
                    167580, 167580, 167580, 167580, 167580],
        "N_c_max": [167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580,
                    167580, 84940.28, 84940.28, 84940.28, 84940.28],
    })


class Q5(Q3):

    data = pd.concat([Q3.data, pd.DataFrame({
        "force type": ["T", "T", "T", "N", "N", "C", "C", "C", "T", "T", "T", "C", "C", "C", "C", "C", "T"],
        "coefficient of P": [1/3, 2/3, 1, 0, 0, 1/3, 2/3, 1, 1/3, 1/3, 1/3, 1, 1, math.sqrt(2)/3, math.sqrt(2)/3,
                             math.sqrt(2)/3, math.sqrt(2)],
    })], axis=1)

    @classmethod
    def calc_member_forces(cls, P):
        p = cls.data.loc[:, ["members", "force type", "coefficient of P"]]
        p["P (N)"] = p["coefficient of P"] * P
        return p


class Q6(Q5):

    @classmethod
    def max_load(cls):

        t = cls.data.loc[cls.data["force type"] == "T"]
        t["P_max"] = t["N_t_max"] / t["coefficient of P"]
        max_load_t = t["P_max"].min()

        c = cls.data.loc[cls.data["force type"] == "C"]
        c["P_max"] = c["N_c_max"] / c["coefficient of P"]
        max_load_c = c["P_max"].min()

        return max_load_t if max_load_t < max_load_c else max_load_c


class Q7:

    data = pd.DataFrame({
        "members": ["AB", "BC", "CD", "DE", "FG", "GH", "HI", "IJ", "AF", "BG", "CH", "DI", "EJ", "AG", "BH", "DH",
                    "EI"],
        "force type": ["T", "T", "T", "T", "N", "C", "C", "N", "T", "T", "N", "C", "N", "C", "C", "T", "C"],
        "coefficient of P": [1/3, 2/3, 2/3, 1, 0, 1/3, 1, 0, 1/3, 1/3, 0, 1/3, 0, math.sqrt(2)/3, math.sqrt(2)/3,
                             math.sqrt(2)/3, math.sqrt(2)],
        "N_t_max": [167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580,
                    167580, 167580, 167580, 167580, 167580],
        "N_c_max": [167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580, 167580,
                    167580, 84940.28, 84940.28, 84940.28, 84940.28],
    })

    @classmethod
    def max_load(cls):

        t = cls.data.loc[cls.data["force type"] == "T"]
        t["P_max"] = t["N_t_max"] / t["coefficient of P"]
        max_load_t = t["P_max"].min()

        c = cls.data.loc[cls.data["force type"] == "C"]
        c["P_max"] = c["N_c_max"] / c["coefficient of P"]
        max_load_c = c["P_max"].min()

        return max_load_t if max_load_t < max_load_c else max_load_c
```

Part B

Q 2.1



$\boxed{\text{Solving reactions}}$

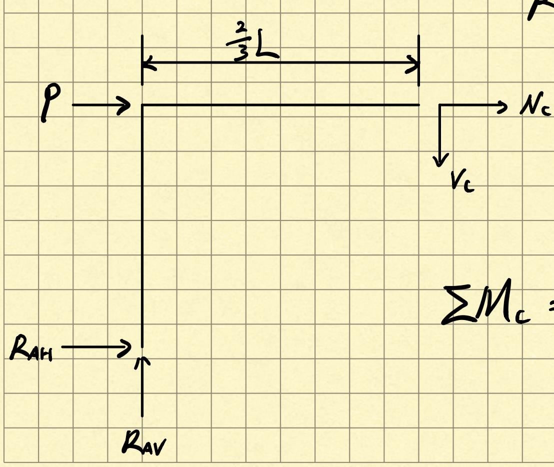


$$\Sigma M_E = 0; \quad P \times H + R_{AV} \times L = 0$$

$$R_{AV} = -\frac{PH}{L}$$

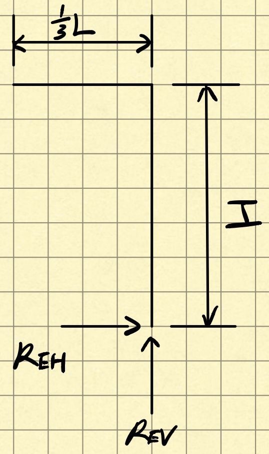
$$\Sigma M_A = 0; \quad P \times H - R_{EV} \times L = 0$$

$$R_{EV} = \frac{PH}{L}$$



$$\Sigma M_c = 0; \quad R_{AV} \times \frac{2}{3}L - R_{AH} \times H = 0$$

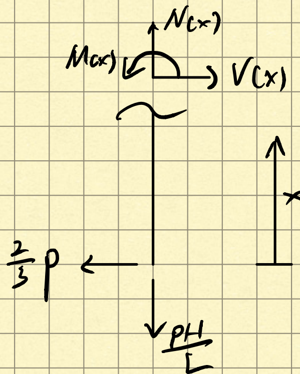
$$R_{AH} = -\frac{2}{3}P$$



$$\sum M_C = 0; \quad -R_{EV} \times \frac{1}{3}L - R_{EH} \times H = 0$$

$$R_{EH} = -\frac{1}{3}P$$

Section ①



$$N(x) - \frac{PH}{L} = 0$$

$$N(x) = \frac{PH}{L}$$

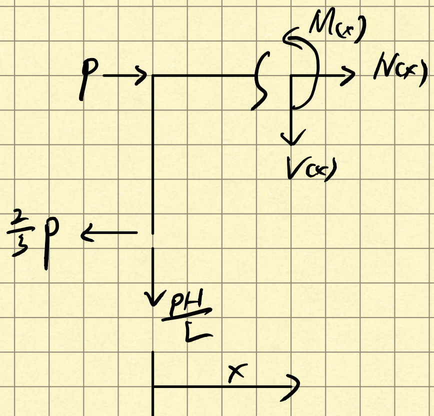
$$V(x) - \frac{2}{3}P = 0$$

$$V(x) = \frac{2}{3}P$$

$$M(x) - \frac{2}{3}Px = 0$$

$$M(x) = \frac{2}{3}Px$$

Section ②



$$N(x) + P - \frac{2}{3}P = 0$$

$$N(x) = -\frac{1}{3}P$$

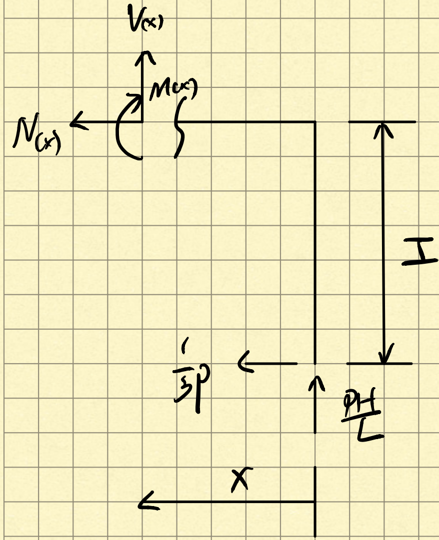
$$-V(x) - \frac{PH}{L} = 0$$

$$V(x) = -\frac{PH}{L}$$

$$M(x) - \frac{2}{3}PH + \frac{PH}{L}x = 0$$

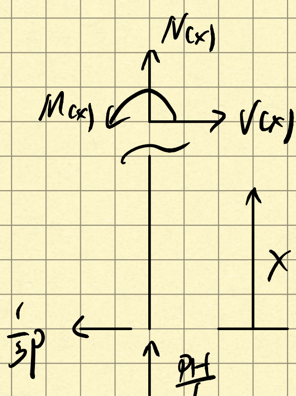
$$M(x) = -\frac{PH}{L}x + \frac{2}{3}PH$$

Section ③



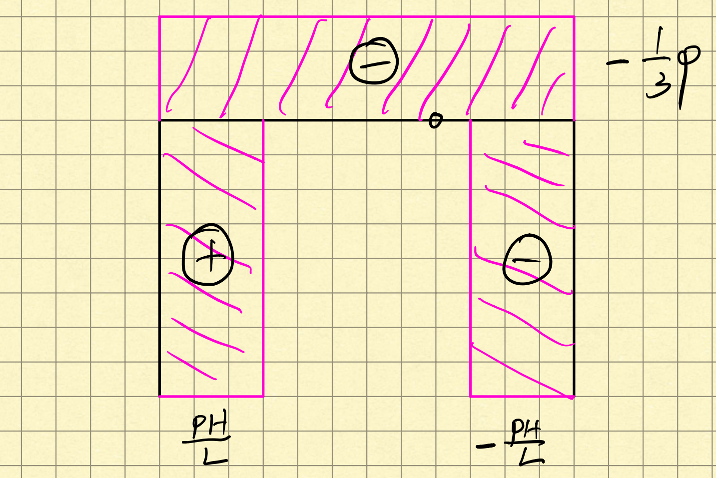
$$-N(x) - \frac{1}{3}P = 0$$
$$N(x) = -\frac{1}{3}P$$
$$V(x) + \frac{PH}{L} = 0$$
$$V(x) = -\frac{PH}{L}$$
$$M(x) - \frac{PH}{L}x + \frac{1}{3}PH = 0$$
$$M(x) = \frac{PH}{L}x - \frac{1}{3}PH$$

Section ④

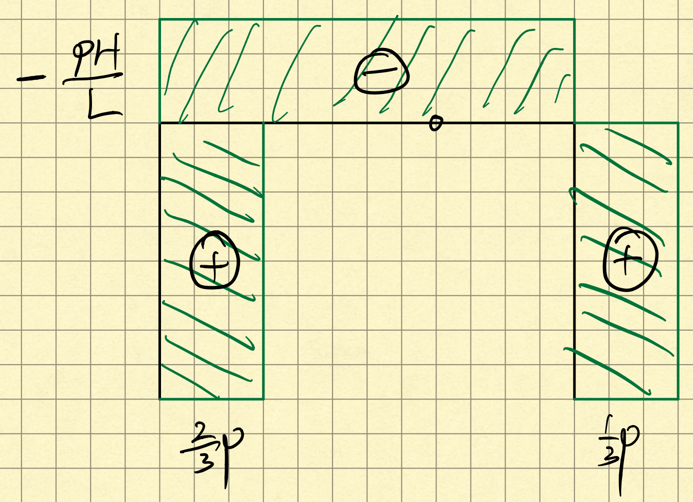


$$N(x) + \frac{PH}{L} = 0$$
$$N(x) = -\frac{PH}{L}$$
$$V(x) - \frac{1}{3}P = 0$$
$$V(x) = \frac{1}{3}P$$
$$M(x) - \frac{1}{3}Px = 0$$
$$M(x) = \frac{1}{3}Px$$

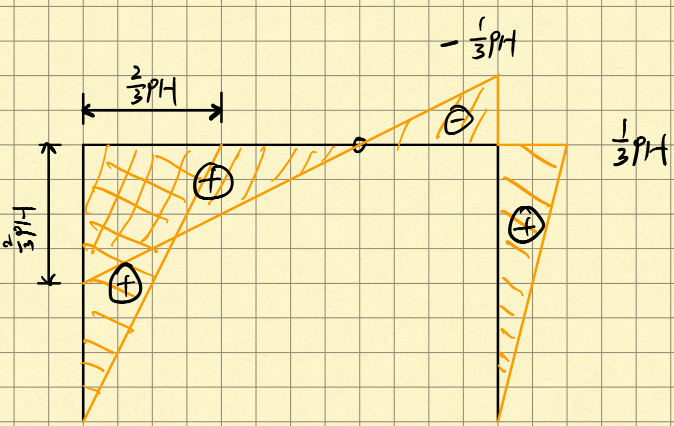
N


$-\frac{1}{3}P$
$\frac{PH}{L}$
$-\frac{PH}{L}$

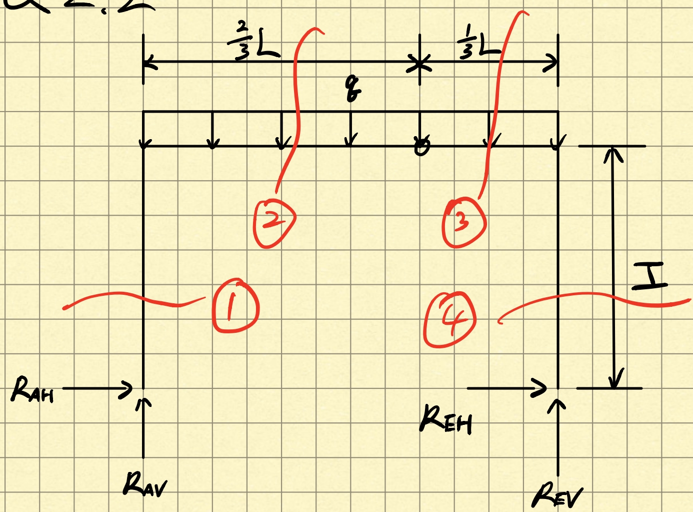
S


$-\frac{PH}{L}$
$\frac{2}{3}P$
$\frac{1}{3}P$

M


$\frac{2}{3}PH$
$-\frac{1}{3}PH$
$\frac{1}{3}PH$
$\frac{2}{3}PH$

Q 2.2



$\boxed{\text{Solving reactions}}$

+ve

$\sum F_V = 0;\ -qL + R_{AV} + R_{EV} = 0$ ——— ①

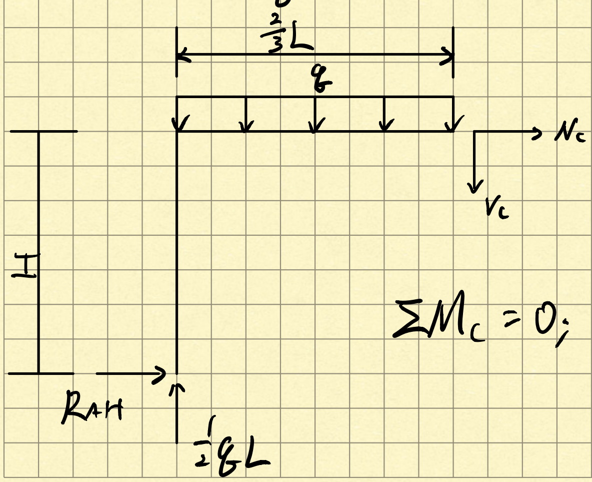
$\sum F_H = 0;\ R_{AH} + R_{EH} = 0$

$\sum M_A = 0;\ qL \times \frac{1}{2}L - R_{EV}L = 0$

$R_{EV} = \frac{1}{2}qL$ ——— ②

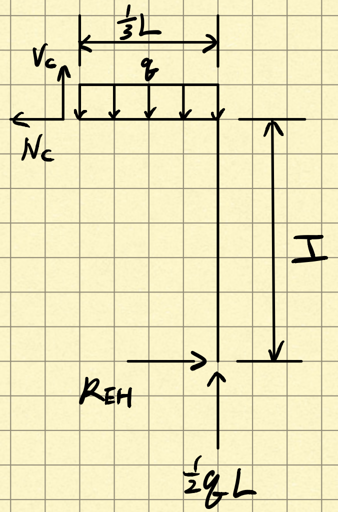
Sub ② into ①

$R_{AV} = \frac{1}{2}qL$



$\sum M_c = 0;\ -\frac{2}{3}qL \times \frac{1}{3}L + \frac{1}{2}qL \times \frac{2}{3}L - R_{AH}H = 0$

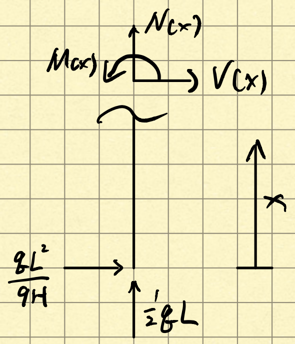
$R_{AH} = \frac{qL^2}{9H}$



$$\Sigma M_c = 0; \quad \frac{1}{3}qL \times \frac{1}{6}L - \frac{1}{2}qL \times \frac{1}{3}L - R_{EH}H = 0$$

$$R_{EH} = -\frac{qL^2}{9H}$$

Section ①



$$N(x) + \frac{1}{2}qL = 0$$

$$N(x) = -\frac{1}{2}qL$$

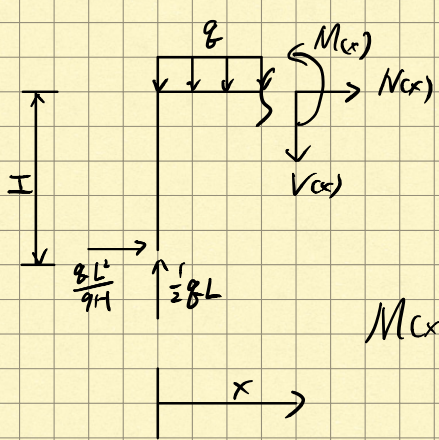
$$V(x) + \frac{qL^2}{9H} = 0$$

$$V(x) = -\frac{qL^2}{9H}$$

$$M(x) + \frac{qL^2}{9H}x = 0$$

$$M(x) = -\frac{qL^2}{9H}x$$

Section ②



$$N(x) + \frac{qL^2}{9H} = 0$$

$$N(x) = -\frac{qL^2}{9H}$$

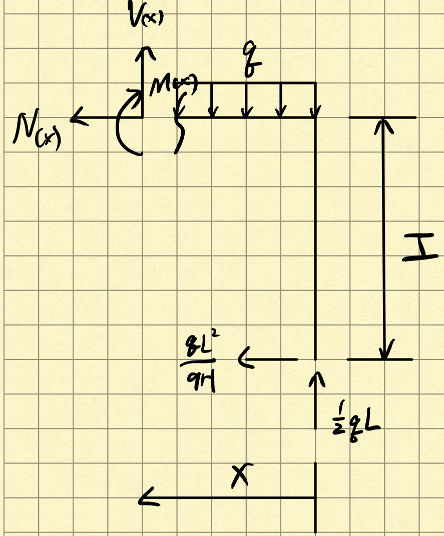
$$\frac{1}{2}qL - V(x) - qx = 0$$

$$V(x) = -qx + \frac{1}{2}qL$$

$$M(x) + qx\frac{x}{2} + \frac{qL^2}{9H}H - \frac{1}{2}qLx = 0$$

$$M(x) = -\frac{1}{2}qx^2 + \frac{1}{2}qLx - \frac{qL^2}{9}$$

Section ③



$$-N(x) - \frac{qL^2}{9H} = 0$$

$$N(x) = -\frac{qL^2}{9H}$$

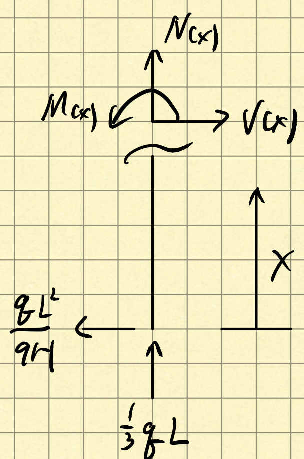
$$V(x) + \frac{1}{2}qL - qx = 0$$

$$V(x) = qx - \frac{1}{2}qL$$

$$M(x) + qx\frac{x}{2} + \frac{qL^2}{9H}H - \frac{1}{2}qLx = 0$$

$$M(x) = -\frac{1}{2}qx^2 + \frac{1}{2}qLx - \frac{qL^2}{9}$$

Section ④



$$N(x) + \frac{1}{2}qL = 0$$

$$N(x) = -\frac{1}{2}qL$$

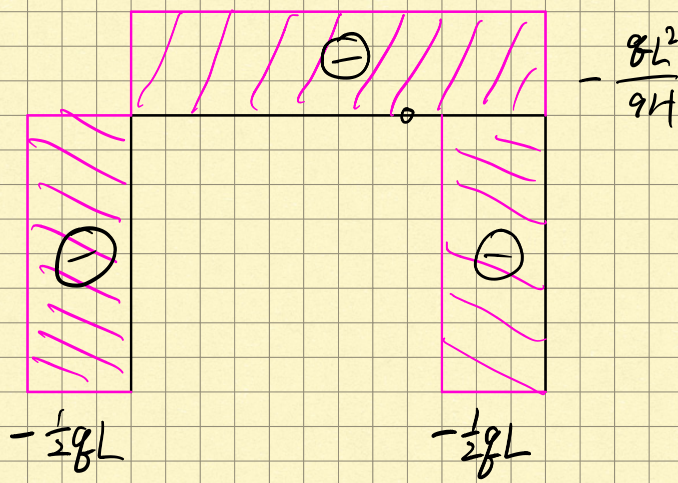
$$V(x) - \frac{qL^2}{9H} = 0$$

$$V(x) = \frac{qL^2}{9H}$$

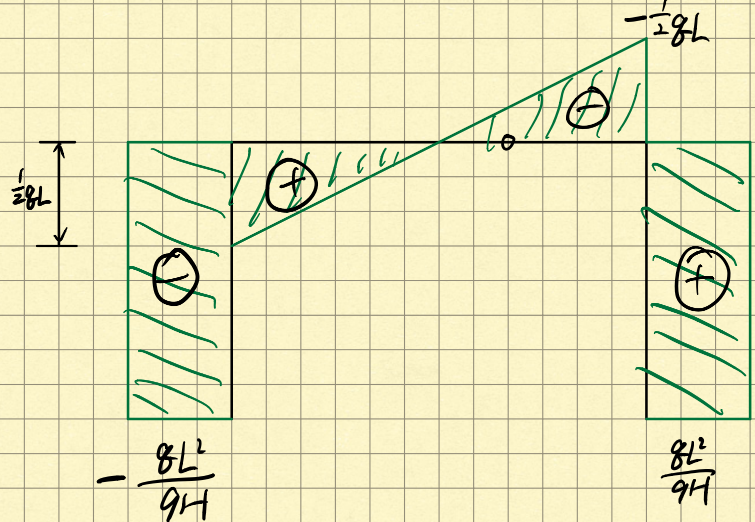
$$M(x) - \frac{qL^2}{9H}x = 0$$

$$M(x) = \frac{qL^2}{9H}x$$

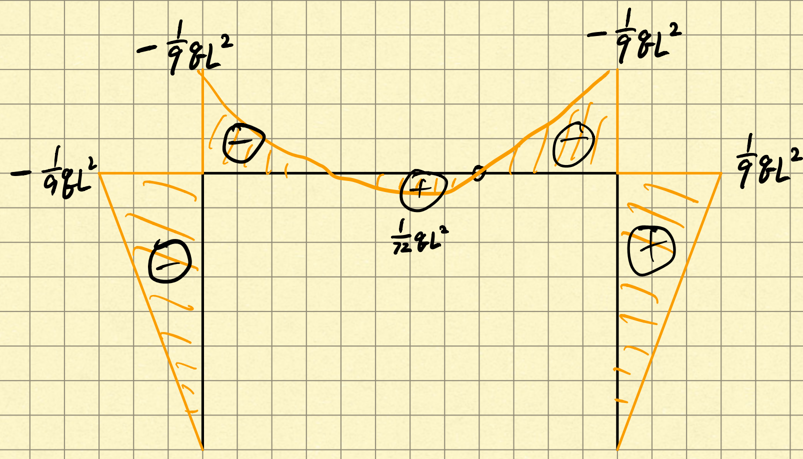
N


- qL²/9H
-1/2 qL
-1/2 qL

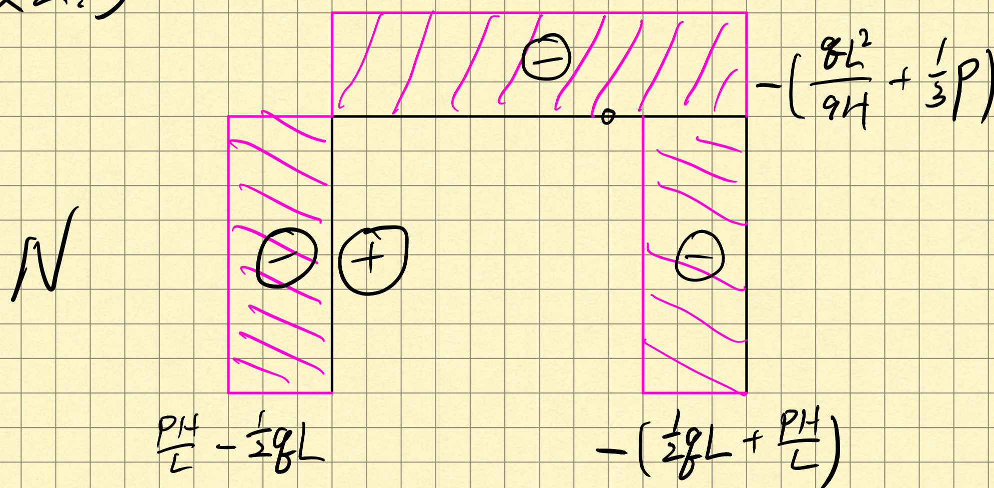
S

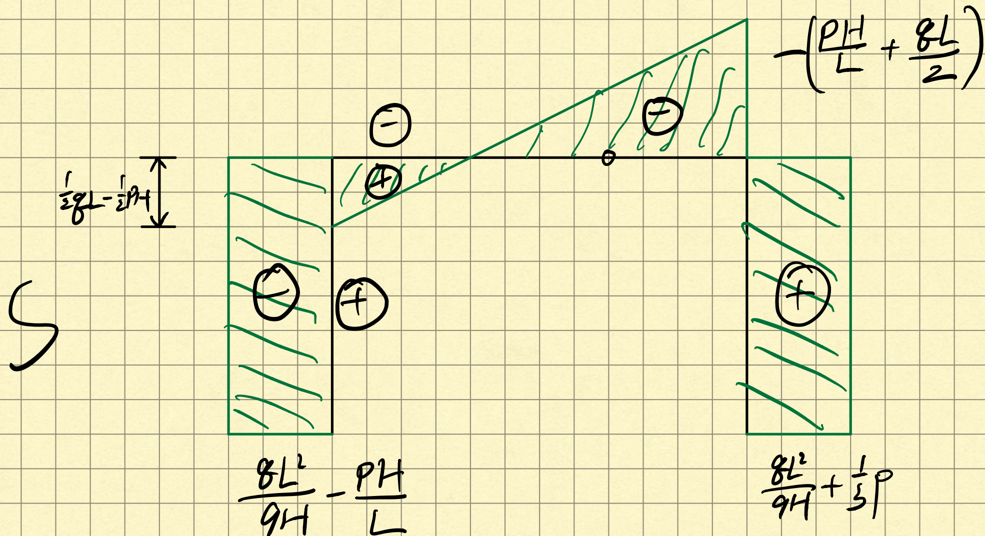

-1/2 qL
1/2 qL
- qL²/9H
qL²/9H

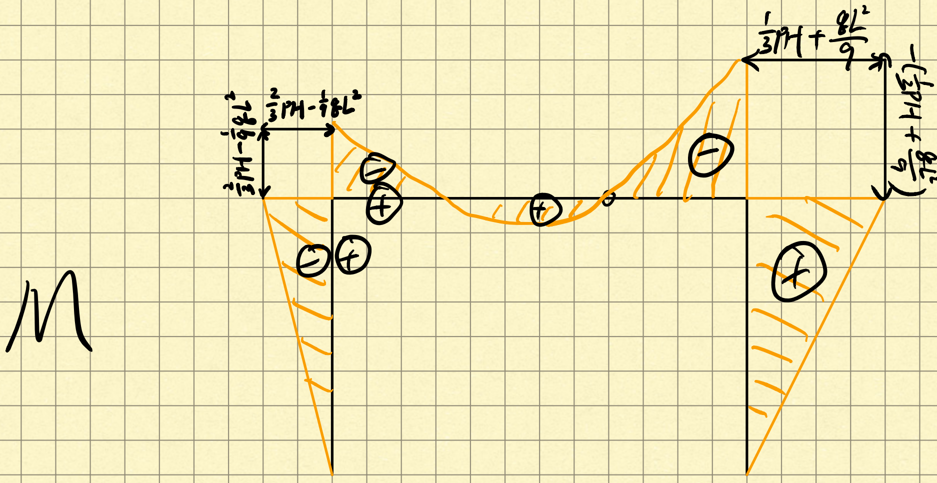
M


-1/9 qL²
-1/9 qL²
-1/9 qL²
1/9 qL²
1/72 qL²

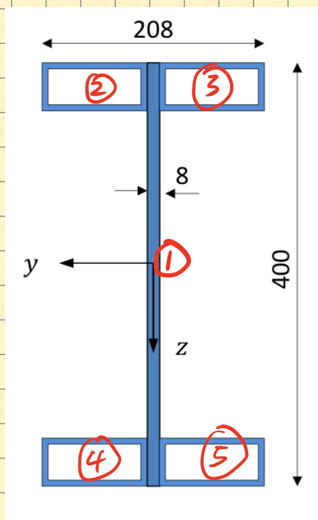
Q2.3


N
−(qL²/9H + 1/3 P)
PH/L − 1/2 qL
−(1/2 qL + PH/L)


S
−(PH/L + qL/2)
qL²/9H − PH/L
qL²/9H + 1/3 P


M
1/3 PH + qL²/9
2/3 PH − 1/9 qL²

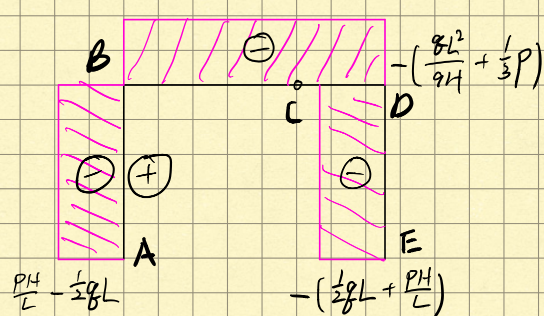
Q2.4

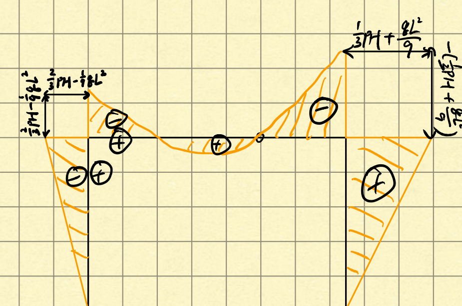


$$A = 8 \times 400 + 4 \times 1810$$
$$= 10440 \text{ mm}^2$$

$$I_y = \sum_{i=1}^{5} \left(I_{yi} + z_i^2 A_i \right)$$
$$= \frac{1}{12} \times 8 \times 400^3$$
$$+ 4\left(4.44 \times 10^6 + (200-25)^2 \times 1810\right)$$
$$= 282151666.7 \text{ mm}^4$$

Q2.5





The point D should be the critical point, since it has both the highest normal force and moment.

Q2.6

$$\sigma_{N_1} = \frac{-\left(\frac{qL^2}{9H} + \frac{1}{3}P\right)}{A}$$

$$= -2.34\,MPa$$

$$\sigma_{N_2} = \frac{-\left(\frac{1}{2}qL + \frac{PH}{L}\right)}{A}$$

$$= -4.79\,MPa$$

$$\sigma_M = \frac{-\left(\frac{1}{3}PH + \frac{qL^2}{9}\right)}{I_y}$$

$$= -43.32\,MPa$$

$$\sigma_{max} = \sigma_{N_2} + \sigma_M$$

$$= -48.11\,MPa$$

Q2.7