Mechanics 20
Project 01
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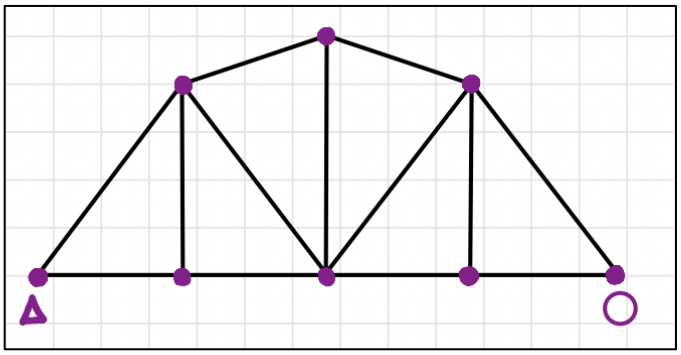
Designing a Truss

Objective:

The objective of the following project is to design and build a truss. Using our truss, we will find its corresponding support reactions and members' internal loads under two different loading conditions.

Part 1: Includes designing the truss and finding the support reactions. Those calculations are initially theoretical.

The design we decided on is the following *Gambrel Truss*:



M = 8 2M = N+R
N = 13 2(8) = 13 +3
R = 3 16 = 16 - Statically determinant.

Variables used:

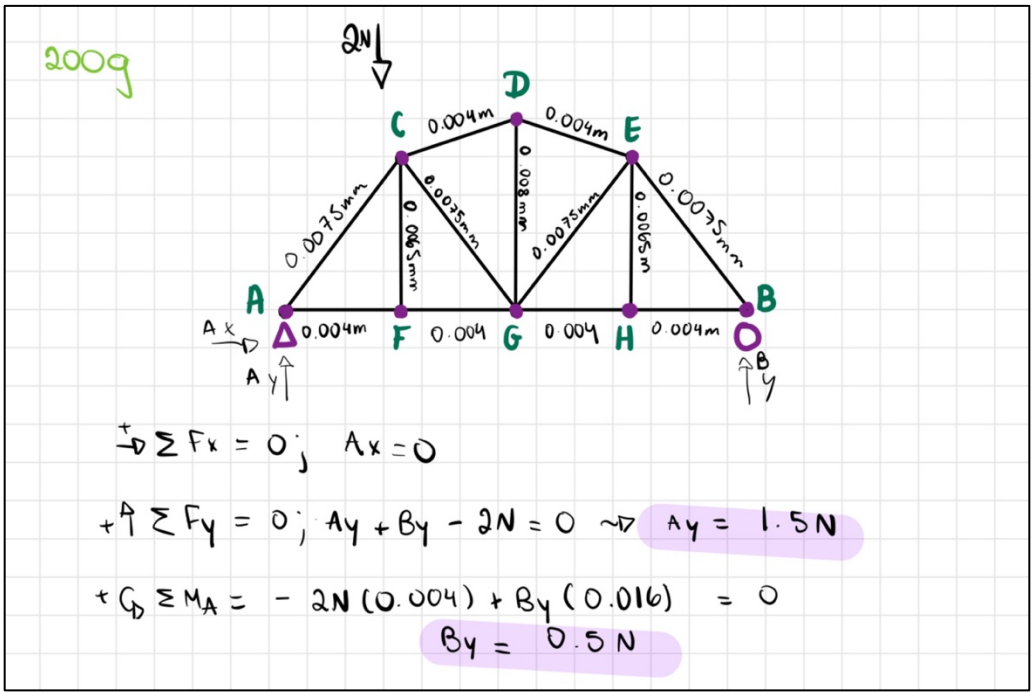
- M is the number of joints.
- N is the number of bars.
- R is the number of support reactions.

The two different loads applied on our truss are the following:

- 200 grams
- 100 grams

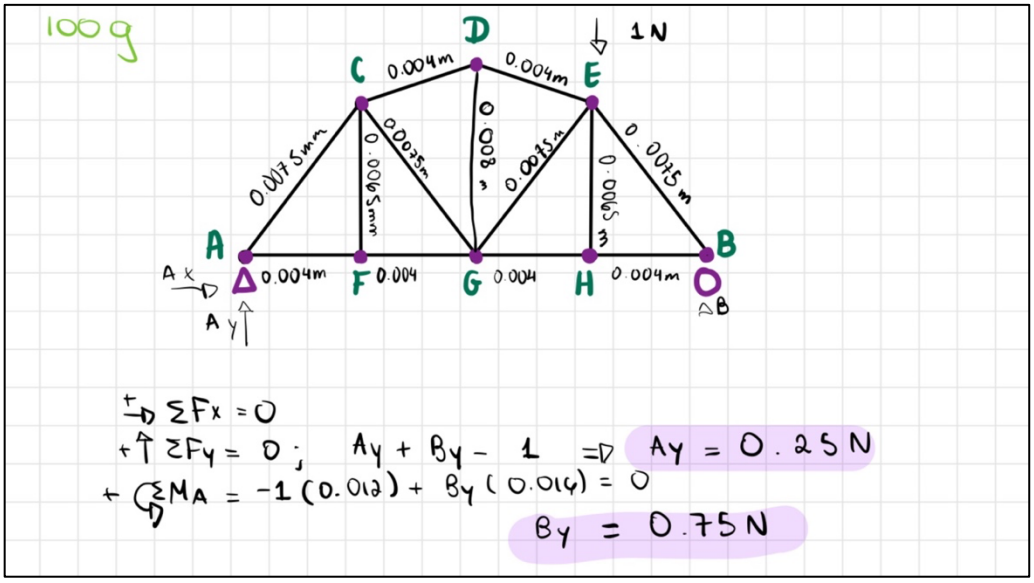
Solving for support reactions.

Here, we solve for the support reactions of the 200-gram (2N) load.



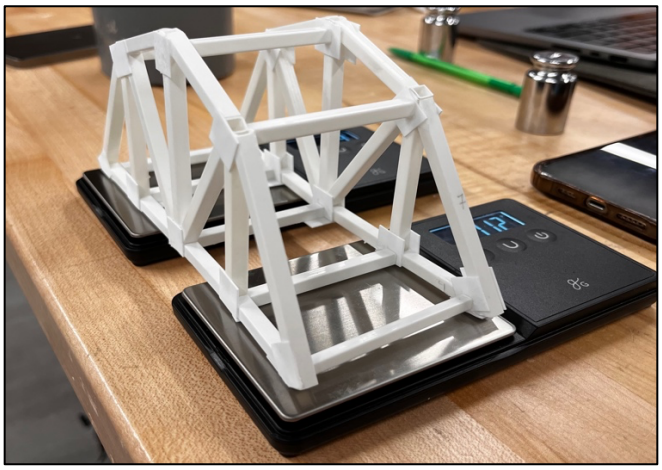
- For our Ay we obtained 1.5N.
- For our By we obtained 0.5N.

Next, we solve for the support reactions of the 100-gram (1N)



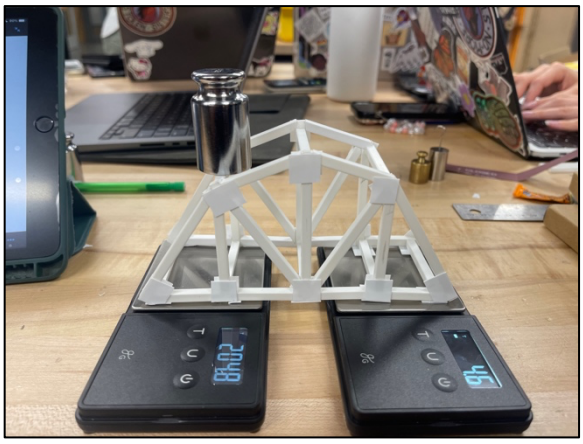
- For our Ay = 0.25N.
- For our By = 0.75N.

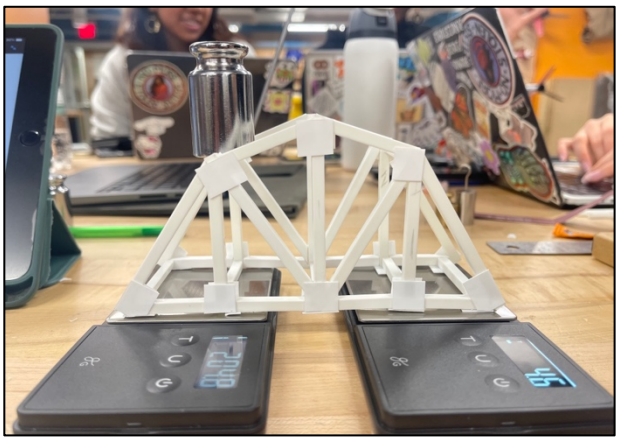
Part 2: Building the truss.



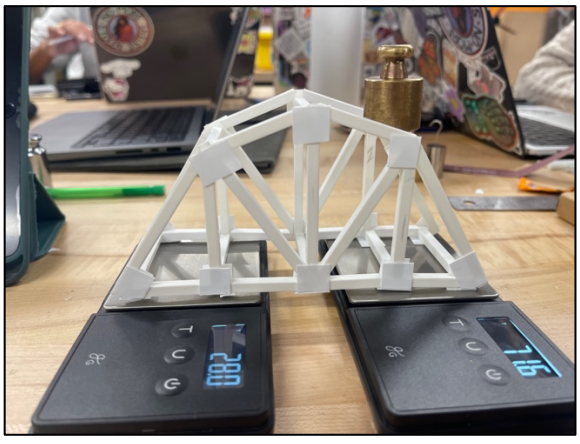
The following pictures show our built truss with two different loads:

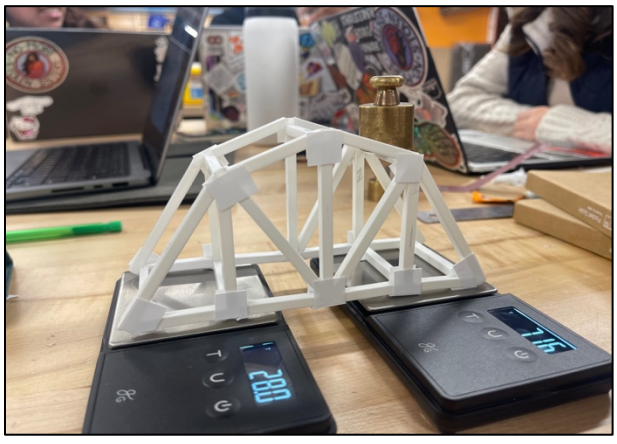
- 200 grams: 204.8 ; 4.6



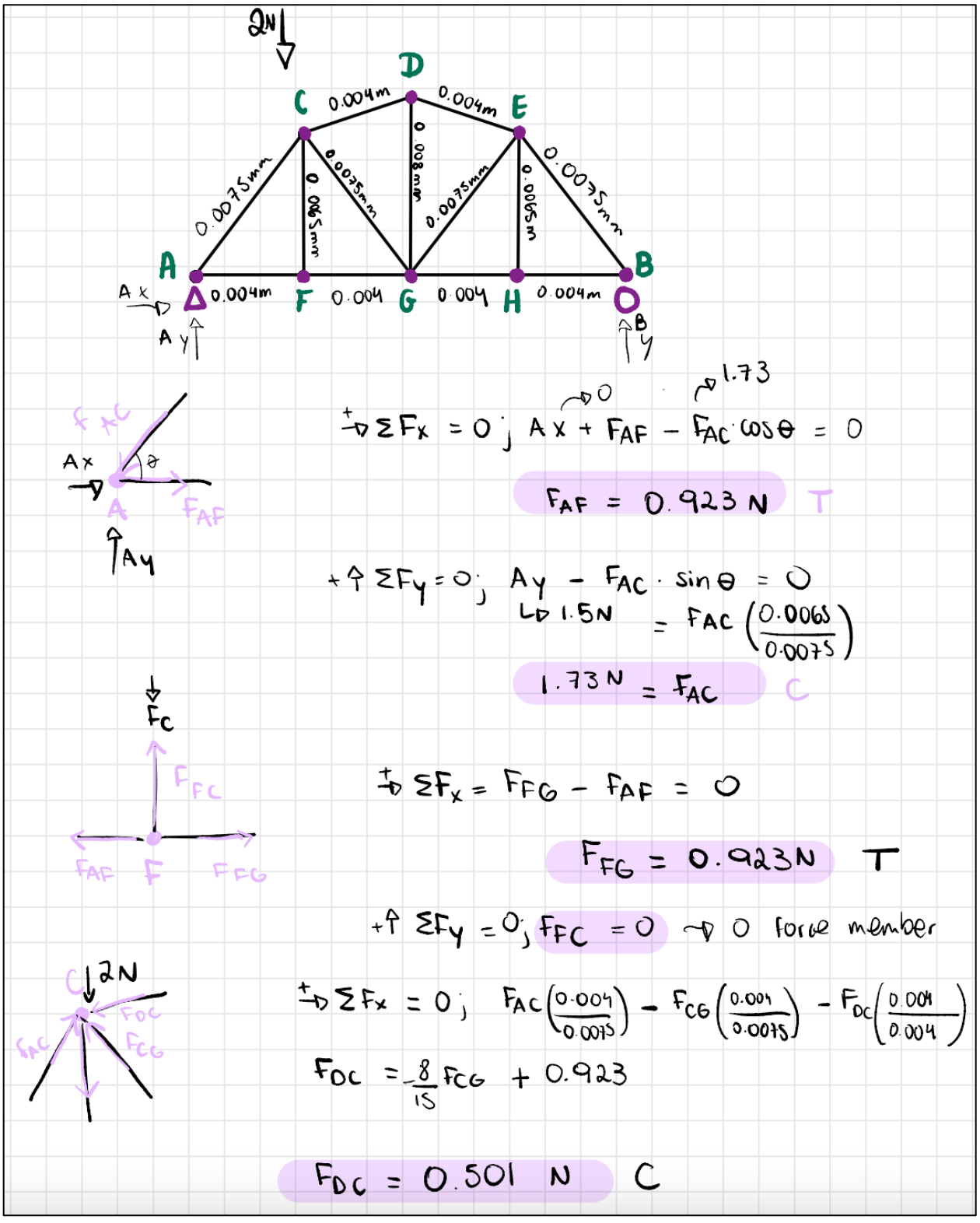


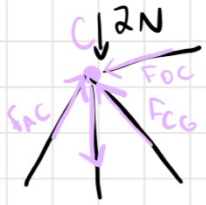
- 100 grams: 28.0 ; 71.6





Solving for the members' internal loads.





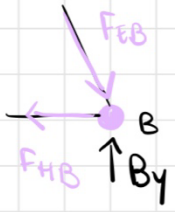
$+\uparrow \Sigma F_y = 0;\ F_{AC}\left(\frac{0.0065}{0.0075}\right) + \underbrace{F_{FC}}_{0} - 2 + F_{CG}\left(\frac{0.0065}{0.0075}\right) - F_{DC}\left(\frac{0.0015}{0.004}\right)$

$\frac{13}{15}$

$1.73\cdot\left(\frac{13}{15}\right) - 2 + F_{CG}\cdot\frac{13}{15} = \left(\frac{8}{15}F_{CG} + 0.923\right)\left(\frac{3}{8}\right)$

$1.499 - 2 + \frac{13}{15}F_{CG} = \left(\frac{3}{15}F_{CG} + 0.346\right)$

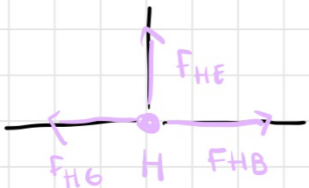
$0.79\ N = F_{CG}$ C



$\overset{+}{\rightarrow}\Sigma F_x = 0;\ F_{EB}\left(\frac{0.004}{0.0075}\right) - F_{HB} = 0 \rightsquigarrow F_{HB} = 0.307\ N$ T

$+\uparrow \Sigma F_y = 0;\ B_y - F_{EB}\left(\frac{0.0065}{0.0075}\right) = 0$

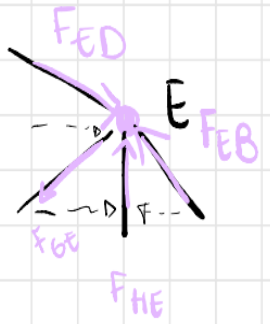
$F_{EB} = 0.576\ N$ C



$\overset{+}{\rightarrow}\Sigma F_x = 0;\ F_{HB} - F_{HG} = 0$

T $F_{HB} = F_{HG} = 0.307\ N$

$+\uparrow \Sigma F_y = 0;\ F_{HE} = 0 \rightsquigarrow$ 0 force member



$\overset{+}{\rightarrow} \Sigma F_x = 0$;

0.576

$$-F_{EB}\cdot\left(\frac{0.004}{0.0075}\right) + F_{DE}\left(\frac{0.004}{0.004}\right) - F_{GE}\left(\frac{0.004}{0.0075}\right) = 0$$

$$F_{DE} = -\frac{8}{15}F_{GE} - 0.3072 \rightsquigarrow -0.5\ N \quad C$$

wrong direction

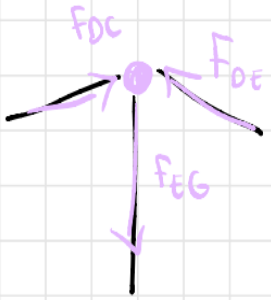
0 ↗ 0.576 ↗

$$+\uparrow \Sigma F_y = 0;\ F_{HE} - F_{GE}\left(\frac{0.0065}{0.0075}\right) + F_{EB}\left(\frac{0.065}{0.075}\right) - F_{ED}\left(\frac{0.0015}{0.004}\right)$$

$$-F_{GE}\frac{13}{15} + 0.499 = \left(\frac{8}{15}F_{GE} - 0.3072\right)\cdot\frac{3}{8}$$

$$-F_{GE}\frac{16}{15} = 0.1152 - 0.499$$

$$F_{GE} = 0.359\ N \quad T$$

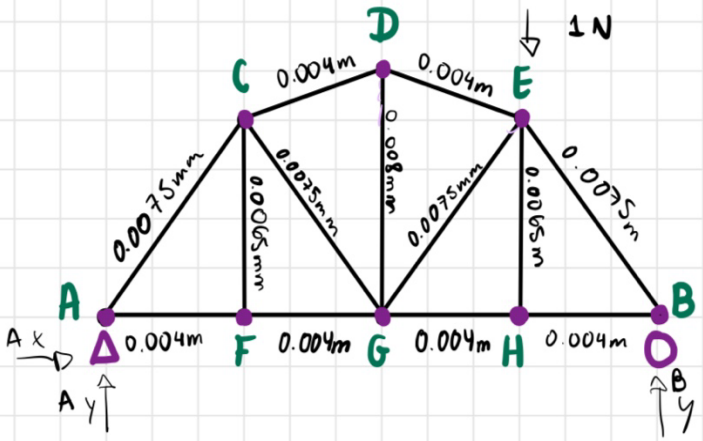


$\overset{+}{\rightarrow} \Sigma F_x = 0$; $-F_{DE}\cdot\left(\frac{0.004}{0.004}\right) + F_{DC}\left(\frac{0.004}{0.004}\right) = 0$

$0 = 0$

$$+\uparrow \Sigma F_y = F_{DE}\left(\frac{0.0015}{0.004}\right) + F_{DC}\left(\frac{0.0015}{0.004}\right) - F_{EG} = 0$$

$$F_{DG} = 0.375\ N \quad T$$



F_{DE}

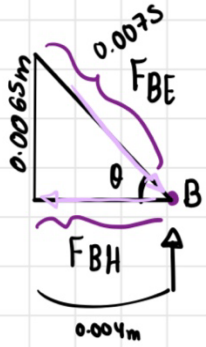
$\overset{+}{\rightarrow} \Sigma F_x = 0 \; ; \; +F_{DE} - F_{EB} + F_{EH}$

$F_{DE}\left(\frac{0.004}{0.004}\right) - \overbrace{0.865\left(\frac{0.004}{0.0075}\right)}^{0.4613} + 0$

$F_{DE} = 0.4613N$

$+\uparrow \Sigma F_y = 0 \; ; -F_{DE} + F_{EG} - F_{EH} - F_{EB} - 1N$

$-0.4613 + F_{EG}\left(\frac{0.0065}{0.0075}\right) + 0 - 0.865\left(\frac{0.004}{0.0075}\right) - 1$



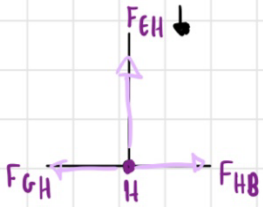
$\overset{+}{\rightarrow} \Sigma F_x = 0 \; ; \; F_{BH} - F_{BE}\cos\theta = 0$

$-F_{BH} + 0.865\left(\frac{0.004}{0.0075}\right) \rightarrow F_{BH} = 0.4613N \; T$

$+\uparrow \Sigma F_y = 0 \; ; \; B_y - F_{BE}\sin\theta = 0$

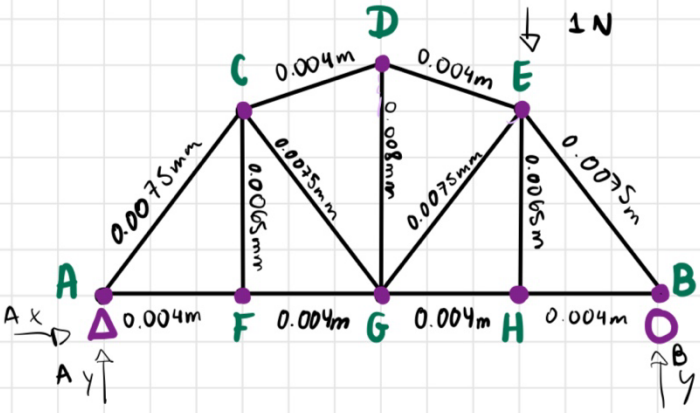
$0.75 - F_{BE}\left(\frac{0.0065}{0.0075}\right) = 0$

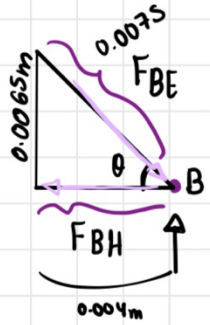
$0.75 = F_{BE}\left(\frac{0.0065}{0.0075}\right) \rightarrow F_{BE} = 0.865N \; C$



$\overset{+}{\rightarrow} \Sigma F_x = 0 \; ; \; F_{HB} - F_{GH} \rightarrow F_{GH} = 0.4613N \; T$

$+\uparrow \Sigma F_y = 0 \; ; \; F_{EH} = 0$





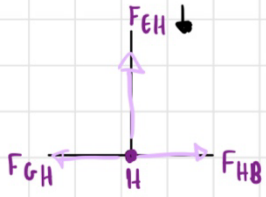
$\xrightarrow{+} \Sigma F_x = 0 \; ; \; F_{BH} - F_{BE} \cos\theta = 0$

$-F_{BH} + 0.865\left(\frac{0.004}{0.0075}\right) \rightarrow F_{BH} = 0.4613N \; T$

$+\uparrow \Sigma F_y = 0 \; ; \; B_y - F_{BE} \sin\theta = 0$

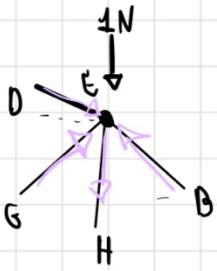
$0.75 - F_{BE}\left(\frac{0.0065}{0.0075}\right) = 0$

$0.75 = F_{BE}\left(\frac{0.0065}{0.0075}\right) \rightarrow F_{BE} = 0.865N \; C$



$\xrightarrow{+} \Sigma F_x = 0 \; ; \; F_{HB} - F_{GH} \rightarrow F_{GH} = 0.4613N \; T$

$+\uparrow \Sigma F_y = 0 \; ; \; F_{EH} = 0$



$$\overset{+}{\rightarrow}\Sigma F_x = F_{DE}\left(\frac{0.004}{0.004}\right) + F_{GE}\left(\frac{0.004}{0.0075}\right) - F_{BE}\left(\frac{0.004}{0.0075}\right)$$

$$0 = F_{DE} + \frac{8}{15}F_{GE} - \frac{8}{15}F_{BE} \quad (F_{BE} \rightarrow 0.865)$$

$$F_{DE} = 0.461 - \frac{8}{15}F_{GE} = \boxed{0.250\ N}\ C$$

$$+\uparrow \Sigma F_y = -F_{DE}\cdot\left(\frac{0.0015}{0.004}\right) + F_{GE}\left(\frac{0.0065}{0.0075}\right) - \overbrace{F_{HE}}^{0} + F_{BE}\left(\frac{0.0065}{0.0075}\right)$$

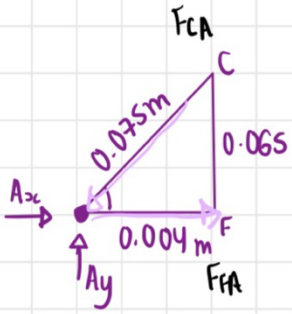
$$= -F_{DE}\cdot\left(\frac{3}{8}\right) + \frac{13}{15}F_{GE} + \underbrace{\frac{13}{15}F_{BE}}_{0.749} \quad (F_{BE} \rightarrow 0.865) - 1$$

$$\left(0.461 - \frac{8}{15}F_{GE}\right)\left(\frac{3}{8}\right) = \frac{13}{15}F_{GE} + 0.749 - 1$$

$$0.172 - \frac{3}{15}F_{GE} = \frac{13}{15}F_{GE} + 0.749 - 1$$

$$\frac{16}{15}F_{GE} = 0.577$$

$$\boxed{F_{GE} = 0.396\ N}\ C$$

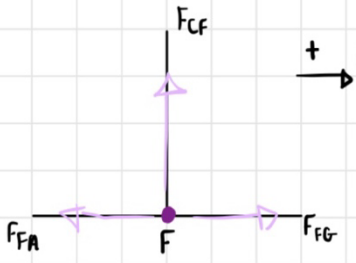


$$\xrightarrow{+}\Sigma F_x = 0 \; ; \; -F_{CA}\left(\frac{0.004}{0.0075}\right) + F_{FA} - A_x$$

$$-0.288\left(\frac{0.004}{0.0075}\right) + F_{FA} \rightarrow F_{FA} = 0.1536\,N \; T$$

$$+\uparrow \Sigma F_y = 0 \; ; \; A_y - F_{CA}\left(\frac{0.0065}{0.0075}\right) = 0$$

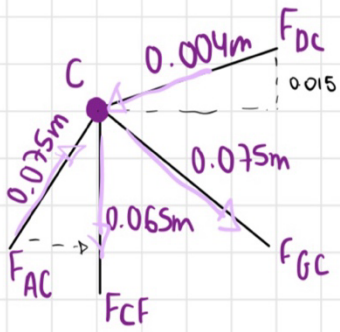
$$0.25 - F_{CA}\left(\frac{0.0065}{0.0075}\right) = 0 \rightarrow F_{CA} = 0.288\,N \; C$$



$$\xrightarrow{+}\Sigma F_x = 0 \; ; \; F_{FG} - F_{FA} = 0$$

$$F_{FG} = 0.1536\,N \; T$$

$$+\uparrow \Sigma F_y = 0 \; ; \; F_{CF} = 0$$



$$\xrightarrow{+}\Sigma F_x = 0 \; ; \; F_{AC}\left(\frac{0.004}{0.0075}\right) + F_{GC}\left(\frac{0.004}{0.0075}\right) - F_{DC}\left(\frac{0.004}{0.004}\right)$$

($F_{AC} \rightarrow 0.288$)

$$= 0.288 \cdot \frac{8}{15} + F_{GC}\left(\frac{8}{15}\right) - F_{DC}$$

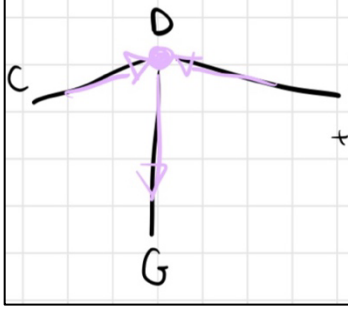
$$F_{DC} = 0.153 + \frac{8}{15}F_{GC} \rightarrow 0.250\,N \; C$$

$$+\uparrow \Sigma F_y = 0 \; ; \; F_{AC}\left(\frac{0.0065}{0.0075}\right) - \cancel{F_{CF}} \; F_{GC}\left(\frac{0.0065}{0.0075}\right) - F_{DC}\left(\frac{0.0015}{0.004}\right)$$

$$0.288 \cdot \frac{13}{15} + \frac{13}{15}F_{GC} = \frac{3}{8}\left(0.153 + \frac{8}{15}F_{GC}\right)$$

$$0.249 - \frac{13}{15}F_{GC} = 0.057 + \frac{3}{15}F_{GC} \rightarrow F_{GC} = 0.18 \; T$$

(wrong direction)



$$\xrightarrow{+}\Sigma F_x = -F_{CE} + F_{CD} = 0$$

$$+\uparrow \Sigma F_y = 0 \; ; \; F_{CD}\left(\frac{0.0015}{0.004}\right) + F_E\left(\frac{0.0015}{0.004}\right) - F_{DG}$$

$$F_{DG} = 0.187\,N \quad T$$

Force members:

200 grams (2N):
- FFC = 0
- FHE = 0

100 grams (1N):
- FEH = 0
- FCF = 0

Forces found:

200 grams (2N):
- FAF = 0.923N (T)
- FAC = 1.73N (C)
- FFG = 0.923N (T)
- FDC = 0.501N (C)
- FCG = 0.79N (C)
- FHB = 0.307N (T)
- FEB = 0.576N (C)
- FHG = 0.307N (T)
- FDE = -0.5N (C)
- FGE = 0.359N (T)
- FDG = 0.375N (T)

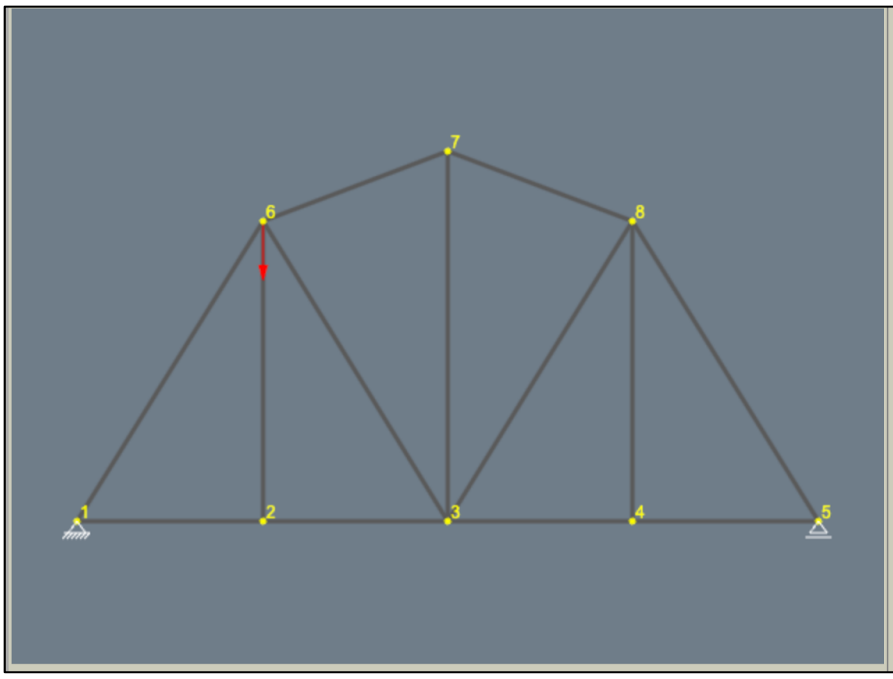
100 grams (1N):
- FBH = 0.4613N (T)
- FBE = 0.865N (C)
- FGH = 0.4613N (T)
- FDE = 0.250N (C)
- FGE = 0.396N (C)
- FFA = 0.1536N (T)
- FCA = 0.288N (C)
- FFG = 0.1536N (T)
- FDC = 0.250N (C)
- FGC = 0.18N (T)
- FDG = 0.187N (T)

Assumptions:

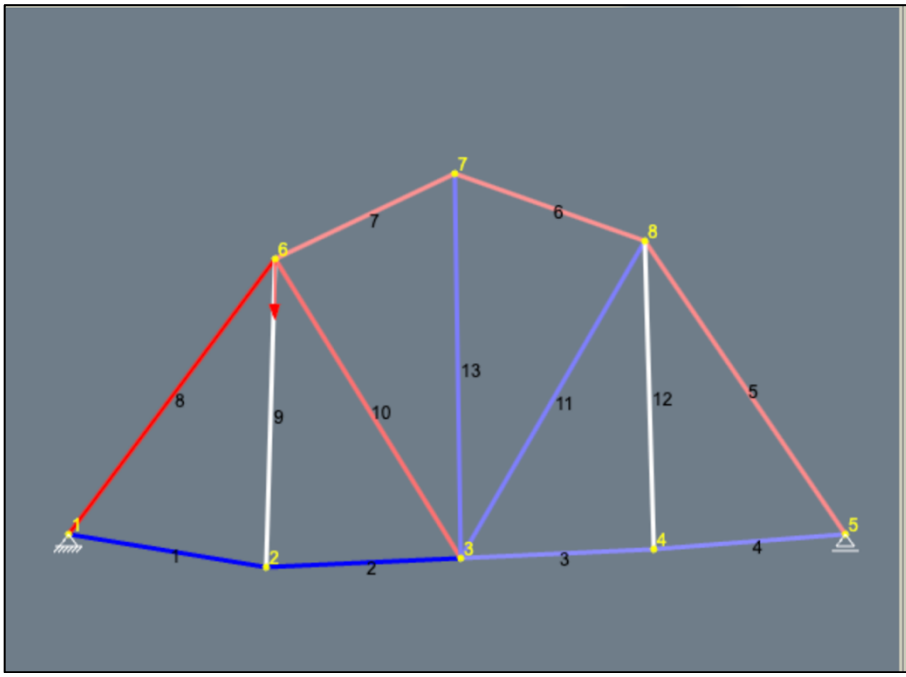
We assumed that in our calculations for the forces using the 200 grams, the value of our FHB = 0.307N would be equal to the value of FHG = 0.307N, a similar assumption with FAF = 0.923N and FFG = 0.923N. Another assumption was made for the forces using the 100 grams. Our FFA = 0.1536N would equal the FFG = 0.1536N, a similar assumption made for FDE = 0.250N and FDC = 0.250N. Thus, our calculations prove those assumptions to be accurate.

Part 4: Checking answers with the online calculator.

- Load of 200 grams



i	F_{ix}	F_{iy}
1		
2		
3		
4		
5		
6	0	-2
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		

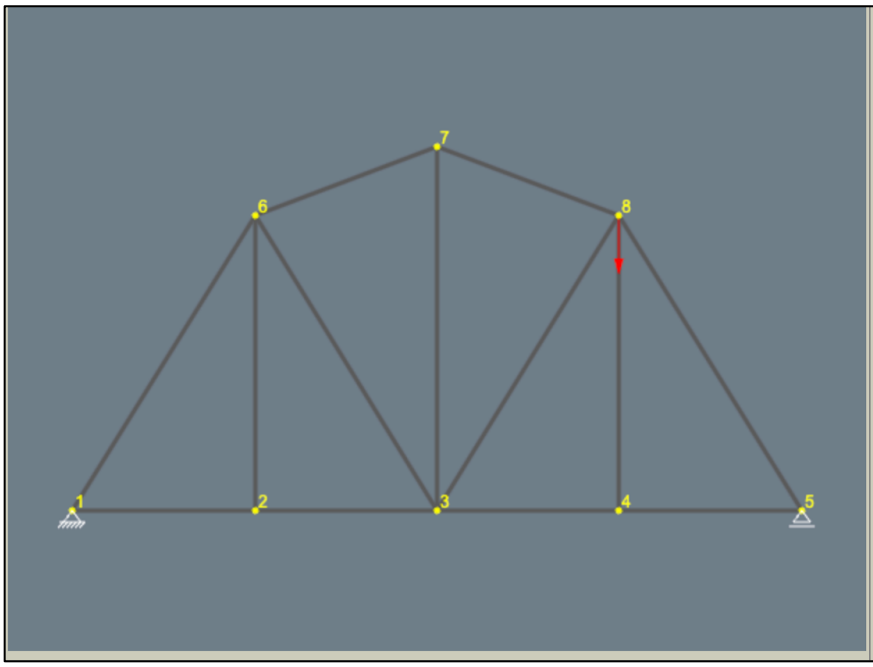


i	N_i	σ_i
1	0.9231	5.769e+6
2	0.9231	5.769e+6
3	0.3077	1.923e+6
4	0.3077	1.923e+6
5	-0.5871	-3.669e+6
6	-0.5340	-3.338e+6
7	-0.5340	-3.338e+6
8	-1.761	-1.101e+7
9	0.000	0.000
10	-0.8072	-5.045e+6
11	0.3669	2.293e+6
12	0.000	0.000
13	0.3750	2.344e+6

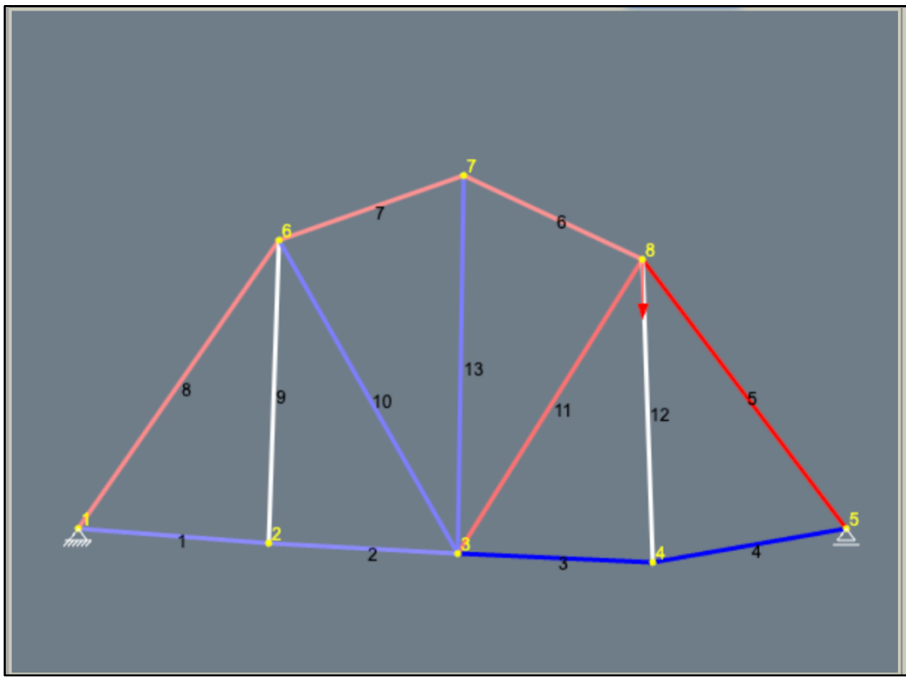
Reaction Forces

i	F_{ix}	F_{iy}
1	0.000	1.500
5	0.000	0.5000

- Load of 100 grams



i	F_{ix}	F_{iy}
1		
2		
3		
4		
5		
6		
7		
8	0	-1
9		
10		
11		
12		
13		
14		
15		
16		



i	N_i	σ_i
1	0.1538	9.615e+5
2	0.1538	9.615e+5
3	0.4615	2.885e+6
4	0.4615	2.885e+6
5	-0.8806	-5.504e+6
6	-0.2670	-1.669e+6
7	-0.2670	-1.669e+6
8	-0.2935	-1.835e+6
9	0.000	0.000
10	0.1835	1.147e+6
11	-0.4036	-2.523e+6
12	0.000	0.000
13	0.1875	1.172e+6

Reaction Forces

i	F_{ix}	F_{iy}
1	0.000	0.2500
5	0.000	0.7500

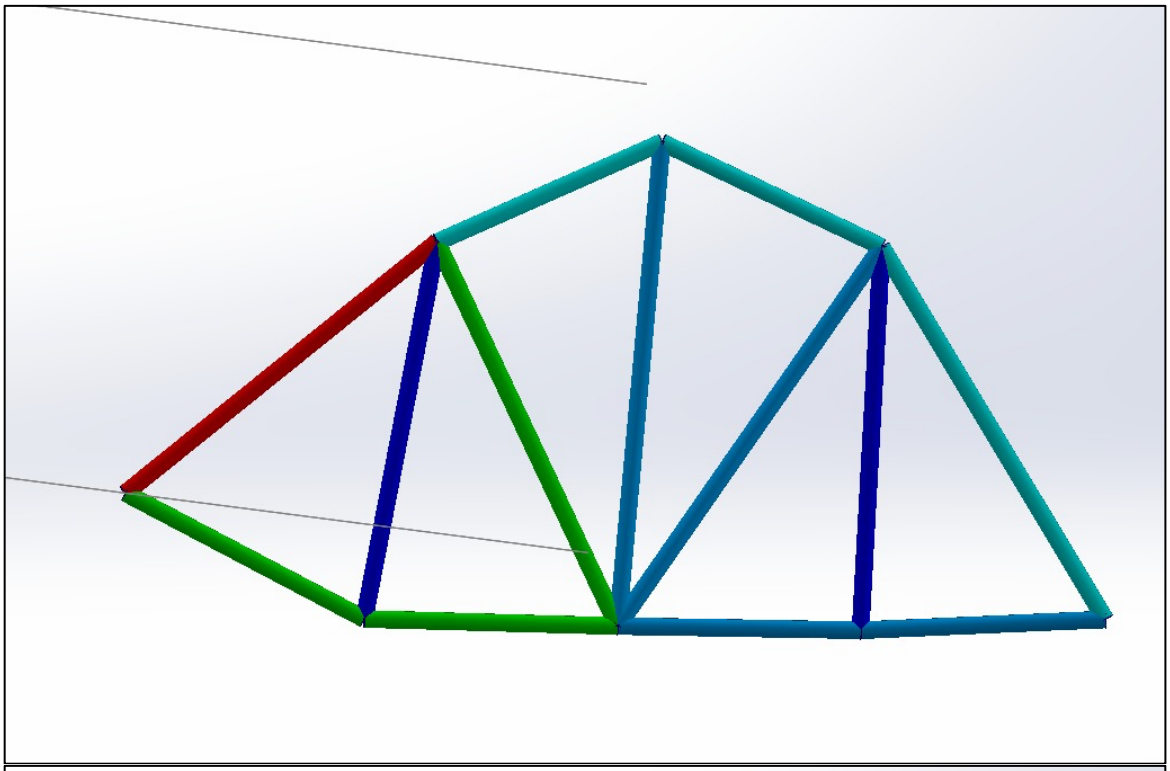
In the following tables, we compare the results mentioned beforehand to those we determined using the online calculator.

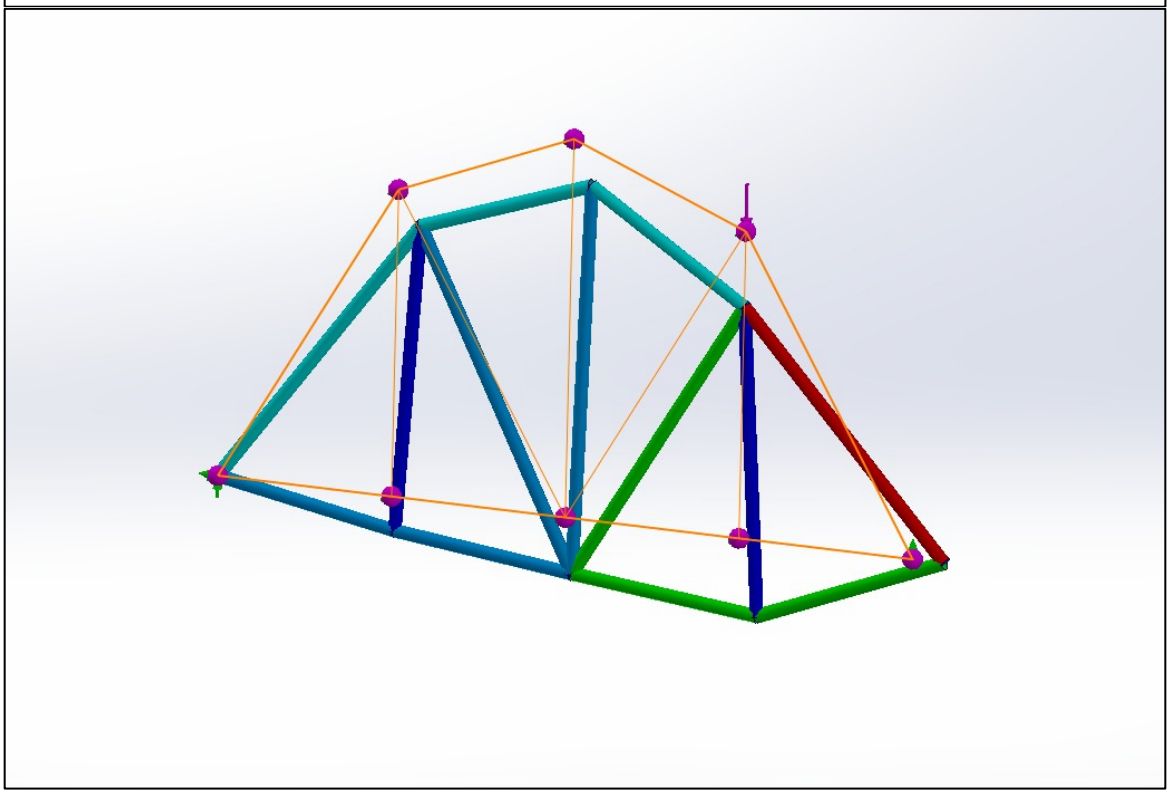
	Load = 200g				
	Theory		Online Truss Calculator		Error
Members	Force (N)	T or C	Force (N)	T or C	
AC	1.73	C	1.761	C	2%
AF	0.923	T	0.923	T	0%
CD	0.501	C	0.534	C	7%
EH	0	-	0	-	0%
CF	0	0	0	-	0%
DG	0.375	T	0.375	C	0%
DE	0.5	C	0.534	C	7%
EG	0.359	T	0.366	T	2%
CG	0.79	T	0.807	T	2%
EB	0.576	C	0.587	C	2%
BH	0.307	T	0.307	T	0%
HG	0.307	T	0.307	T	0%
FG	0.923	T	0.923	T	0%

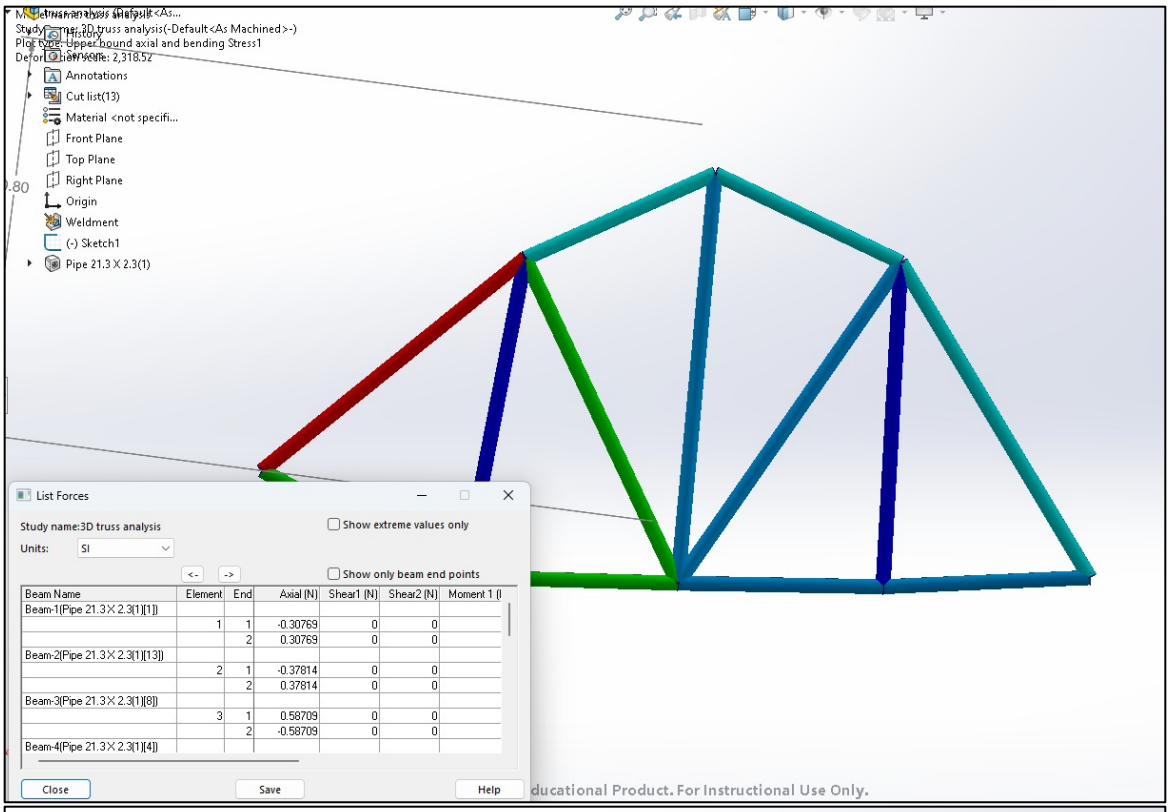
	Load = 100g				
	Theory		Online Truss Calculator		Error
Members	Force (N)	T or C	Force (N)	T or C	
AC	0.288	C	0.293	C	2%
AF	0.153	T	0.153	T	0%
CD	0.25	C	0.267	C	7%
EH	0	-	0	-	0%
CF	0	0	0	-	0%
DG	0.187	T	0.187	T	0%
DE	0.25	C	0.267	C	7%
EG	0.396	C	0.403	C	2%
CG	0.18	T	0.183	T	2%
EB	0.865	C	0.88	C	2%
BH	0.461	T	0.461	T	0%
HG	0.461	T	0.461	T	0%
FG	0.153	T	0.153	T	0%

Part 5: Finite Element Analysis (FEA)

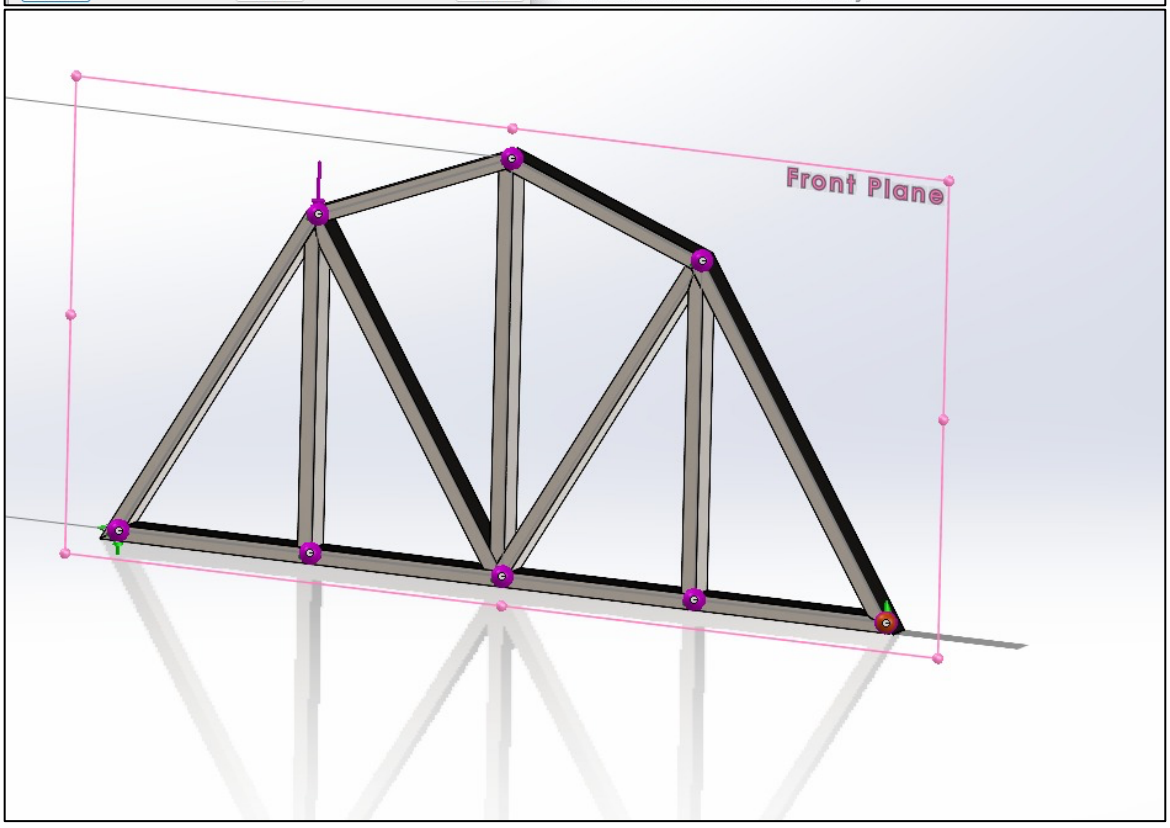
The following pictures show the design of the truss using SolidWorks.







Beam Name	Element	End	Axial (N)	Shear1 (N)	Shear2 (N)	Moment 1 (I
Beam-1(Pipe 21.3X 2.3(1)[1])						
	1	1	-0.30769	0	0	
		2	0.30769	0	0	
Beam-2(Pipe 21.3X 2.3(1)[13])						
	2	1	-0.37814	0	0	
		2	0.37814	0	0	
Beam-3(Pipe 21.3X 2.3(1)[8])						
	3	1	0.58709	0	0	
		2	-0.58709	0	0	
Beam-4(Pipe 21.3X 2.3(1)[4])						



In the following tables, we compare the results we determined to the results that we obtained through the FEA.

	Load = 200 g				
	Theory		FEA		Error
Members	Force (N)	T or C	Force (N)	T or C	
AC	1.73	C	1.76	C	2%
AF	0.923	T	0.923	T	0%
CD	0.501	C	0.533	C	6%
EH	0	-	3.58E-15	-	#DIV/0!
CF	0	0	6.56E-15	-	#DIV/0!
DG	0.375	T	0.378	T	1%
DE	0.5	C	0.533	C	7%
EG	0.359	T	0.365	T	2%
CG	0.79	T	0.809	T	2%
EB	0.576	C	0.587	C	2%
BH	0.307	T	0.307	T	0%
HG	0.307	T	0.307	T	0%
FG	0.923	T	0.923	T	0%

	Load = 100 g				
	Theory		FEA		Error
Members	Force (N)	T or C	Force (N)	T or C	
AC	0.288	C	0.293	C	2%
AF	0.153	T	0.153	T	0%
CD	0.25	C	0.266	C	6%
EH	0	-	3.96E-15	-	#DIV/0!
CF	0	0	1.57E-15	-	#DIV/0!
DG	0.187	T	0.189	T	1%
DE	0.25	C	0.266	C	6%
EG	0.396	C	**0.404**	**C**	2%
CG	0.18	T	0.182	T	1%
EB	0.865	C	0.88	C	2%
BH	0.461	T	0.461	T	0%
HG	0.461	T	0.461	T	0%
FG	0.153	T	0.153	T	0%

In these tables, we determine the support reactions.

Support Reactions (N)			
Supports →	**Pin**		**Roller**
From ↓	**x-comp**	**y-comp**	**y-comp**
Theory	0	1.5	0.5
Experiment	0	2	0.4
Online Calculator	0	1.5	0.5
FEA	0	1.5	0.5

Support Reactions (N)			
Supports →	**Pin**		**Roller**
From ↓	**x-comp**	**y-comp**	**y-comp**
Theory	0	0.25	0.75
Experiment	0	0.28	0.71
Online Calculator	0	0.25	0.75
FEA	0	0.25	0.75

Conclusion:

To conclude, our report highlights some of the key issues that impacted our experiment's accuracy. Firstly, there was an initial measurement error where we incorrectly calculated one side of the truss to be 6.3mm (0.0063m) and rounded it to 6.5mm (0.0065m), which contributed to the observed error percentages in our tables.

In addition, during the process of weighing our truss with the load of 200 grams, we didn’t realize that we hadn’t reset the weight balance, which eventually resulted in different values in the reaction forces of the experiment and the calculated ones. However, to try and fix that problem, we went back to the Lab and tried to weigh it again to fix the error, the weight balances were both out of batteries and didn’t work. Therefore, we were left with the only choice of working with the data that we had in hand.

Despite the challenges mentioned, this project offered valuable insights into the process of calculating truss forces and their real-world applications. It emphasized the significance of accurate theoretical calculations and the importance of cross-referencing our work with online calculators. Lastly, the project provided a better understanding of how to identify any miscalculations in our work through the Finite Element Analysis, which is a method that can be applied to similar projects in the future.