Preliminary Design Report

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EK301 Section A5

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Introduction:

Our objective is to design a simple truss capable of supporting a minimum applied load of 32 oz at a horizontal distance of 9-12 inches away from the pin support. Our virtual budget is under $305. Analyzing the truss to determine the maximum failure loads while taking into account budget limits requires lengthy calculations and a greater possibility for human error to occur.

In order to verify our iterative designs more efficiently, we were motivated to develop a computer program that functions to analyze a truss. The program will accept an input file with a connection matrix, a reaction force matrix, joint location vectors, and an applied load vector. The output will display the support reaction forces, the internal tensile force in each member, the external load, and the cost of the truss. We will use this information to brainstorm and improve experimental designs until we find two strong truss designs that adhere to the specifications. By comparing factors such as the maximum buckling load and cost efficiency, we will determine the optimal truss design.

Method and Analysis:

- The computational approach was broken down into several components. First, the parameters for the members and joints were defined in a large matrix that presented the relationship between members and connecting joints. In addition, matrices of reaction forces in the horizontal and vertical components were defined in relation to the joints they act on. This similar matrix was defined for the applied load as well. The x-y coordinates of each joint were also defined in separate matrices. Then the equilibrium equations of the horizontal and vertical components were defined using the x-y coordinates and the length of each member. Using linear algebra techniques, a T matrix was constructed where the tension/compression forces of each member and the reaction forces were presented.
- P_{crit} was determined using the fitted equation found using all the data from classmates of EK301. The equation used was $P_{crit} = 3654.533*L^{-2.119}$, where L is the length of each member in inches, and P_{crit} is the maximum load in oz before a member will buckle. The uncertainty range for each P_{crit} value is ± 1.685 oz (95%). Knowing that the force in each member is directly proportional to the applied weight (W_l), with its relationship represented by $T_M = R_M * W_l$, the constant R could be calculated and will remain

independent from the applied load. Thus, the maximum load that could be applied to each member before they buckle ($W_{failure}$) is $-P_{crit}/R$. The member with the smallest $W_{failure}$ will determine the maximum load that can be exerted on the entire truss body.

Table 1. The calculated forces for each member for example truss design and their corresponding force types. The handwritten result (Appendix A) and the computer-ran result are aligned with one another and follow the result in the table below.

Member #	Force magnitude (N)	Force type
1	16.667	Compression
2	16.667	Tension
3	0	-
4	23.570	Compression
5	16.667	Tension
6	16.667	Compression
7	11.785	Tension
8	8.333	Tension
9	0	-
10	11.785	Compression
11	8.333	Tension
12	0	-
13	8.333	Compression

(The output of the computational code for the Example Problem test is displayed in Appendix B)

Results:

Truss Design I

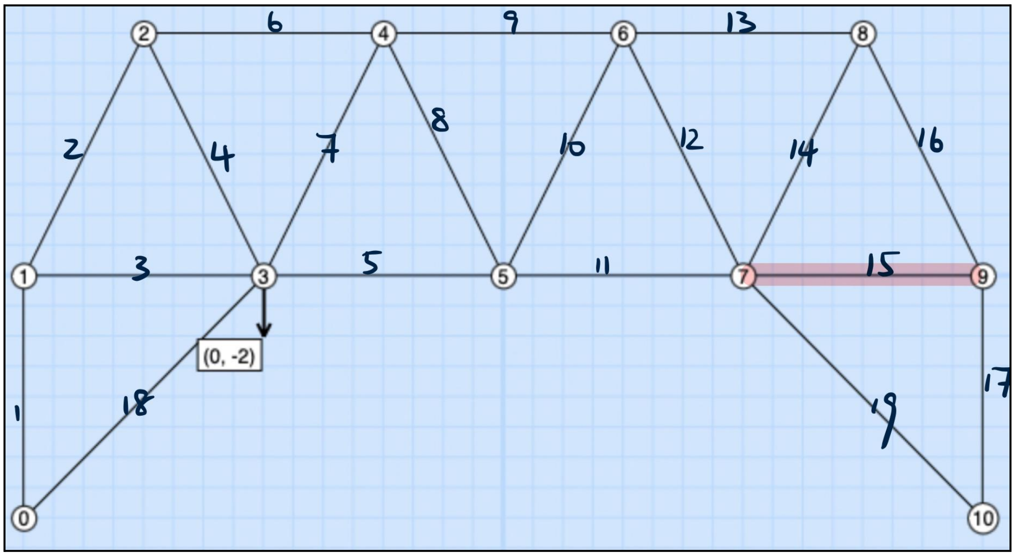


Figure 1: Visual representation of the first truss design.

Nodes

#	x [in]	y [in]
0	-16	-8
1	-16	0
2	-12	8
3	-8	0
4	-4	8
5	0	0
6	4	8
7	8	0
8	12	8
9	16	0
10	16	-8

Add new node

Members

#	Nodes	Length [in]	Force [lbf]
1	0-1	8	
2	1-2	8.944	
3	1-3	8	
4	2-3	8.944	
5	3-5	8	
6	2-4	8	
7	3-4	8.944	
8	4-5	8.944	
9	4-6	8	
10	5-6	8.944	
11	5-7	8	
12	6-7	8.944	
13	6-8	8	
14	7-8	8.944	
15	7-9	8	
16	8-9	8.944	
17	9-10	8	
18	0-3	11.314	
19	7-10	11.314	

External Forces

Node	Fx [lbf]	Fy [lbf]
3	0	-2

*Reaction forces at a support

Figure 2: Tables for the node locations, member qualities and external forces of the first truss design.

```
>> trussanalysisfinal(C, Sx, Sy, X, Y, L, appliedLoad)
\% EK301, Section A5, Group 16: Kelly Y., Gaby P., Adam Y. 11/16/23xx.

Load: 32.00 oz

Member forces in oz
m1: 24.000 (C)
m2: 26.833 (C)
m3: 12.000 (T)
m4: 26.833 (T)
m5: 20.000 (T)
m6: 24.000 (C)
m7: 8.944 (T)
m8: 8.944 (C)
m9: 16.000 (C)
m10: 8.944 (T)
m11: 12.000 (T)
m12: 8.944 (C)
m13: 8.000 (C)
m14: 8.944 (T)
m15: 4.000 (T)
m16: 8.944 (C)
m17: 8.000 (C)
m18: 0.000 ( )
m19: 0.000 ( )

Reaction forces in oz:
Sx1: 0.00
Sy1: 24.00
Sy2: 8.00

Cost of truss: $276.18
Theoretical max load/cost ratio in oz/$: 0.6196

The following member(s) will buckle first: 15

The maximum load (at which those members fail) is: -171.13
```

Figure 3: Computed prediction of the force in each member from a given vertical load at the specified load joint.

- **Member to buckle first**: Member 15 (highlighted in Figure 1)
- **Maximum load the truss can support ($W_{Failure}$):** 171 ounces
- **Cost:** $276.18
- **Load-to-Cost Ratio:** 0.620

Truss Design II

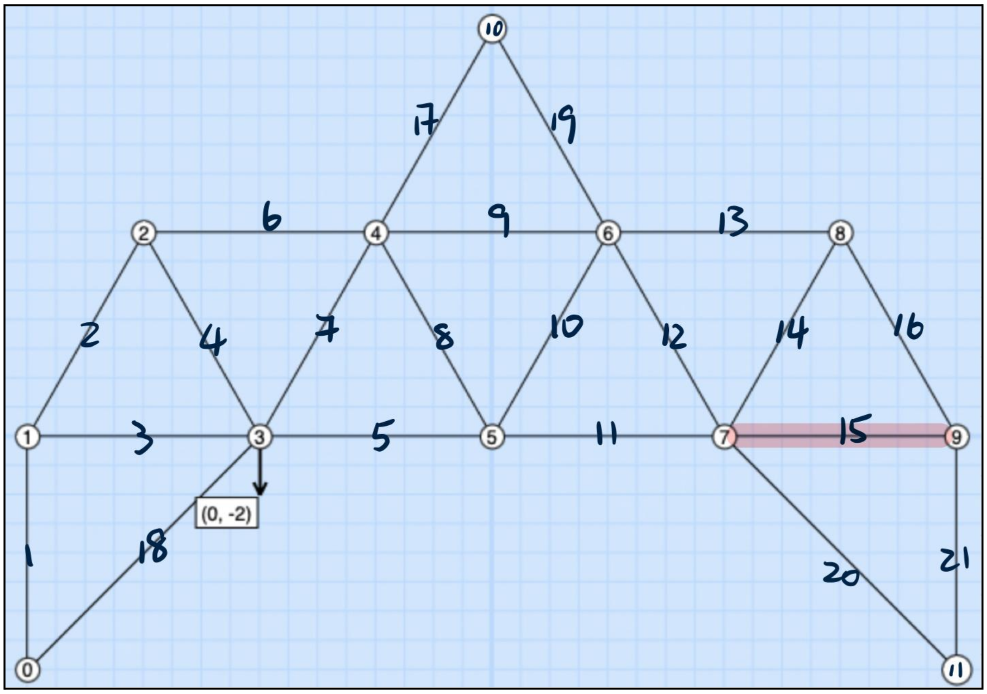


Figure 4: Visual representation of the second truss design.

Nodes

#	x [in]	y [in]
0	-16	-8
1	-16	0
2	-12	7
3	-8	0
4	-4	7
5	0	0
6	4	7
7	8	0
8	12	7
9	16	0
10	16	-8
11	0	14
Add new node		

Members

#	Nodes	Length [in]	Force [lbf]
1	0-1	8	
2	1-2	8.062	
3	1-3	8	
4	2-3	8.062	
5	3-5	8	
6	2-4	8	
7	3-4	8.062	
8	4-5	8.062	
9	4-6	8	
10	5-6	8.062	
11	5-7	8	
12	6-7	8.062	
13	6-8	8	
14	7-8	8.062	
15	7-9	8	
16	8-9	8.062	
21	9-10	8	
18	0-3	11.314	
20	7-10	11.314	
17	4-11	8.062	
19	6-11	8.062	

External Forces

Node	Fx [lbf]	Fy [lbf]
3	0	-2

*Reaction forces at a support

Figure 5: Tables for the node locations, member qualities and external forces of the second truss design.

```
>> trussanalysisfinal(C, Sx, Sy, X, Y, L, appliedLoad)
\% EK301, Section A5, Group 16: Kelly Y., Gaby P., Adam Y. 11/16/23xx.

Load: 32.00 oz

Member forces in oz
m1: 24.000 (C)
m2: 27.642 (C)
m3: 13.714 (T)
m4: 27.642 (T)
m5: 21.499 (T)
m6: 27.429 (C)
m7: 12.285 (T)
m8: 11.926 (C)
m9: 16.000 (C)
m10: 8.944 (T)
m11: 12.000 (T)
m12: 8.944 (C)
m13: 8.000 (C)
m14: 8.944 (T)
m15: 4.000 (T)
m16: 8.944 (C)
m17: 0.000 ( )
m18: 0.000 ( )
m19: 0.000 ( )
m20: 0.000 ( )
m21: 8.000 (C)

Reaction forces in oz:
Sx1: 0.00
Sy1: 24.00
Sy2: 8.00

Cost of truss: $298.04
Theoretical max load/cost ratio in oz/$: 0.5742

The following member(s) will buckle first: 15

The maximum load (at which those members fail) is: -171.13
```

Figure 6: Computed prediction of the force in each member from a given vertical load at the specified load joint.

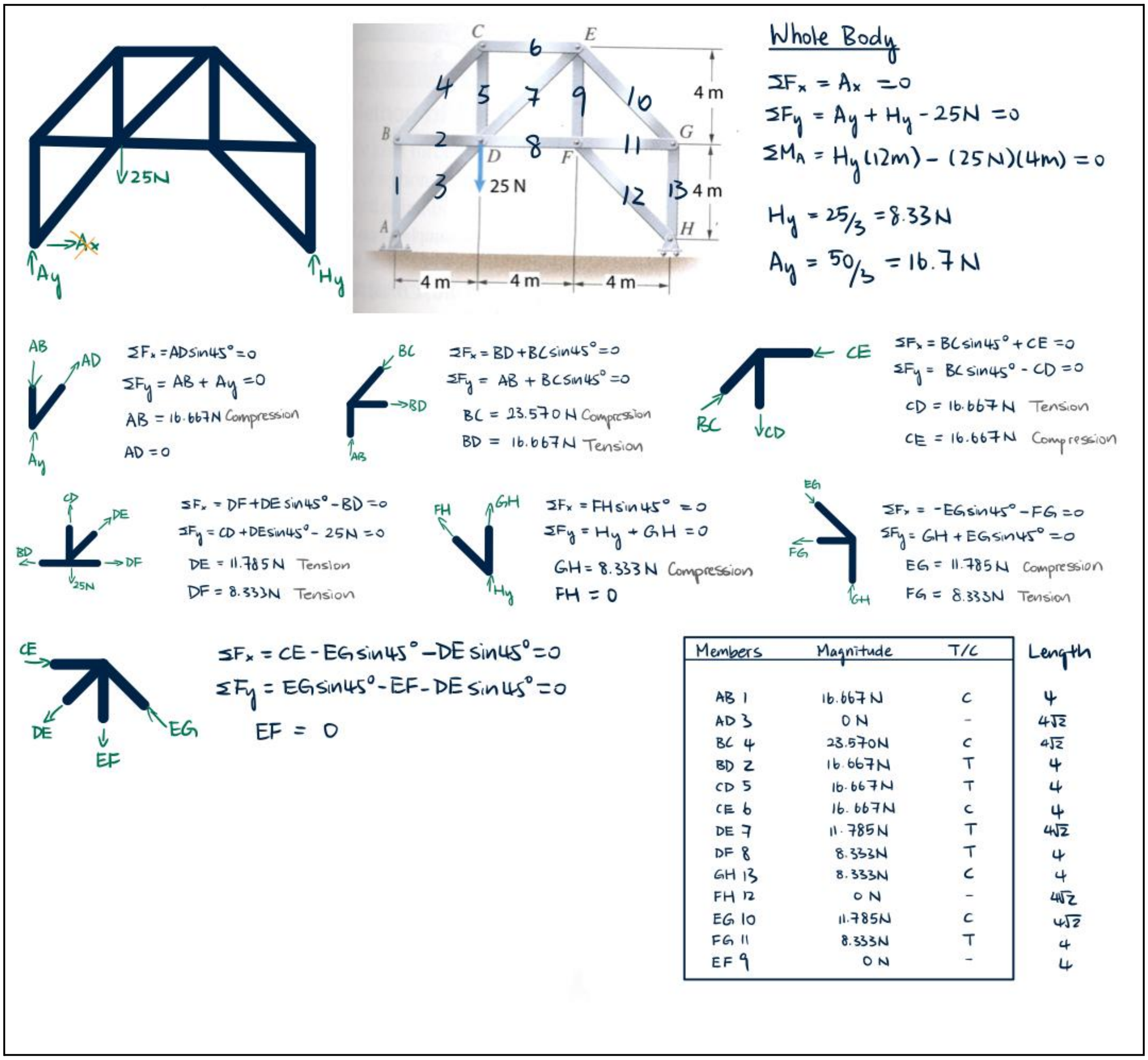
- **Member to buckle first**: Member 15 (highlighted in Figure 4)
- **Maximum load the truss can support ($W_{Failure}$):** 171 ounces
- **Cost:** $298.04
- **Load-to-Cost Ratio:** 0.574

Discussion and Conclusion:

Our results suggest that Truss I is the more effective simple truss design. The designs support the same maximum loads, however, Truss I results to be more cost-effective than Truss II. Truss I costs $276.18 with a 0.642 load-to-cost ratio, while Truss II costs $298.04 with a 0.574 load-to-cost ratio. To further improve Truss I, we would redesign the structure to exclude the zero force members involved (members 18 & 19). This would maximize the weight distribution and overall strength of the Truss, while also making it more cost effective. Since our cost is reasonably below the budget, we could utilize the remaining funds to implement more joints and shorter members. It may also be possible to scale down the size of our truss further, because as we found in the buckling lab, shorter members are able to withstand a larger applied load.

Appendix:

A. Hand Written Example Problem



B. Computer Output of Example Problem

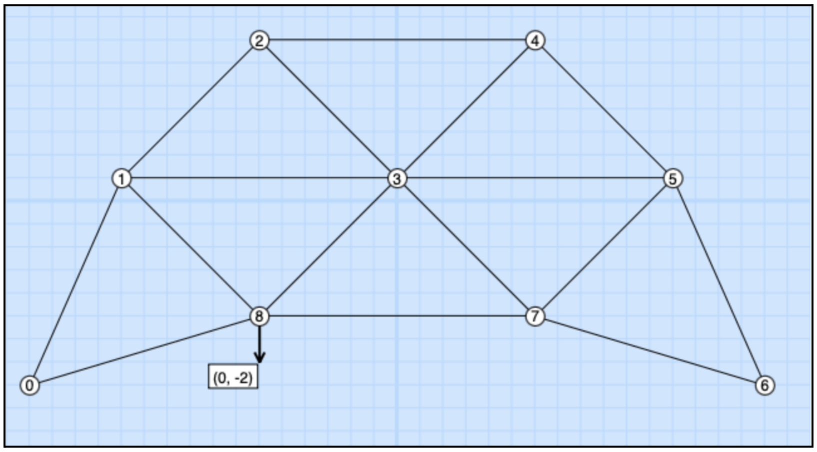
```
\% EK301, Section A5, Group #: Kelly, Gaby, Adam 11/16/23xx.

Load: 25.00 N

Member forces in N
m1: 16.667 (C)
m2: 16.667 (T)
m3: 0.000 ( )
m4: 23.570 (C)
m5: 16.667 (T)
m6: 16.667 (C)
m7: 11.785 (T)
m8: 8.333 (T)
m9: 0.000 ( )
m10: 11.785 (C)
m11: 8.333 (T)
m12: 0.000 ( )
m13: 8.333 (C)

Reaction forces in N:
Sx1: 0.00
Sy1: 16.67
Sy2: 8.33
```

C. Other Unused Truss Design



Nodes

#	x [in]	y [in]
0	-16	-8
1	-12	1
2	-6	7
3	0	1
4	6	7
5	12	1
6	16	-8
7	6	-5
8	-6	-5

Add new node

Members

#	Nodes	Length [in]	Force [lbf]
0	0-1	9.849	
1	0-8	10.44	
2	1-2	8.485	
3	1-3	12	
4	1-8	8.485	
5	2-4	12	
6	2-3	8.485	
7	3-4	8.485	
8	3-5	12	
9	3-7	8.485	
10	4-5	8.485	
11	5-6	9.849	
12	5-7	8.485	
13	6-7	10.44	
14	7-8	12	
15	3-8	8.485	

External Forces

Node	Fx [lbf]	Fy [lbf]
8	0	-2

*Reaction forces at a support

Members: 15, Joints: 8, Member length: 8.485-12 in, Load: 2 lb, Cost: \$246.46 < \$305, Vertical Span: 15 in, Horizontal Span: 32 in, Load to pin: (10, 3, 10.44). Reason for discard: did not obey the relationship M = 2J-3.