Lab 1

ENSC 384

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1 Finite Element Analysis

This section of the lab examines several different truss designs using finite element analysis. Sample 2D truss designs were evaluated using a provided MATLAB program in order to determine the axial forces and deflections in each member of the truss when various loads were applied. These sample designs, referenced by a design number throughout this report, are shown in figure 1. The strengths and weaknesses of these truss designs are discussed. The load/deflection characteristics and the efficiency (stiffness/weight) of each structure is examined and used to compare each design. Five additional designs are considered and compared to those provided on the basis of overall efficiency. Finally, the results of an analytical solution, calculated using the method indeterminate structures, is presented and compared to the numerical approximations generated by the finite element analysis.

1.1 Methods and Results

Basic results

Table 1 shows initial results of the finite element analysis for each of the provided five designs. The overall deflection in addition to the maximum tension and compression of any member is provided for a varying range of Young's modulus. Furthermore, table 2 lists the deflection and maximum tension and compression in any member for design two over a range of applied forces.

Net Stiffness and Efficiency

The relative stiffness of each truss is given in table 3. It can clearly be seen that the fifth design has the greatest efficiency by a large margin. The primary feature distinguishing it from the other designs is its height of 10 cm instead of the other designs having heights of 5 cm.

Buckling

A factor of safety with regards to buckling is an important design requirement. Table 4 lists the lengths of every member in each design which experiences compression. The force for which a member of the specified length will buckle is given. Eulerian buckling for columns is assumed with a theoretical fixity constant of 1, corresponding to two pined ends. The maximum force predicted by the finite element analysis in any member of the given length is listed which may then be used to compute the factor of safety. For an additional factor of safety, the smallest Young's modulus for brass is also assumed (96 GPa).

Indeterminate Structure Theory

Structures three (figure 2) and five (figure 3) were analyzed using indeterminate structure theory. Tables 5 and 6 show the respective forces and deflections experienced by each member. The applied load was assumed to be 1 N and the smallest Young's modulus (96 GPa) was used. The overall deflection in the third design (figure 2) was calculated to be 0.00558 mm, less than the 0.0107 mm predicted by the finite element analysis. The overall deflection in the fifth design (figure 3) was seen to be 0.00554 mm, slightly greater than the 0.0036 mm predicted by the finite element analysis.

1.2 New Designs

Five additional designs were generated to compare against the provided designs. They may be seen in figures 4, 5, 6, 7 and 8. Design seven (figure 5) was an attempt to improve the most efficient design given (design five) by reducing the material used. Designs eight and ten (figures 6 and 8) are similar to the designs provided but have different heights. The efficiency for each design is presented in table 7

1.3 Discussion

Design Features

When doing the two-dimensional FEA of the test trusses, we determined that the last design, number 5, was the most efficient truss in terms of deflection and tolerance to buckling. We therefore used this truss as a starting point for our truss design. The features in design 5 that make for an effective design are maximizing the allowable height, balancing stiffness vs. weight, and ensuring individual truss members have similar safety factors (as is the case for design 5 - Table 4).

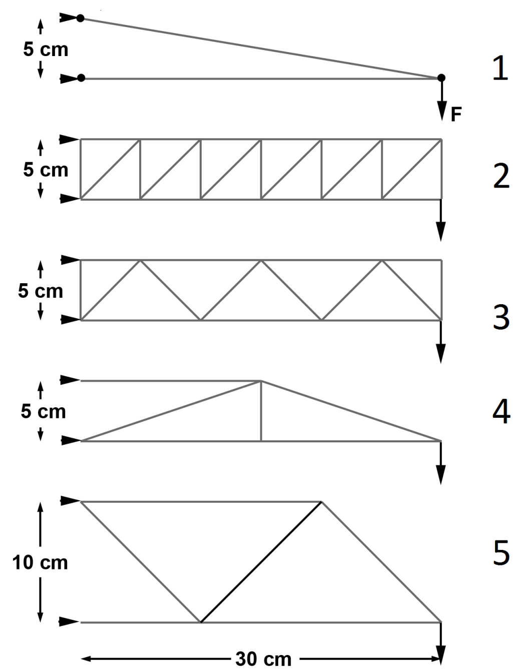

Figure 1: Provided Designs With Reference Numbers

Table 1: Initial Results, Deflection for 1 N, and Effect of Young's Modulus

Design	E	Deflection
1	96	0.029 mm
	103	0.027 mm
	110	0.025 mm
2	96	0.0112 mm
	103	0.0103 mm
	110	0.0097 mm
3	96	0.0107 mm
	103	0.010 mm
	110	0.0094 mm
4	96	0.0148 mm
	103	0.0138 mm
	110	0.0129 mm
5	96	0.0036 mm
	103	0.0034 mm
	110	0.0032 mm

Table 2: Force Variation - Design Two (E = 100 GPa)

Applied force	Maximum Tension (Force)	Maximum Compression (Force)	Endpoint Deflection
10 N	60 N	50 N	0.107 mm
20 N	120 N	100 N	0.214 mm
30 N	180 N	150 N	0.320 mm
40 N	240 N	200 N	0.427 mm

Table 3: Stiffness and Efficiency

Design	Stiffness			Efficiency		
	Applied Force	Deflection	Stiffness	Material Length	Weight	Efficiency
1	1 N	0.029 mm	34.5	0.604 m	40.6 g	849
2	1 N	0.0112 mm	89.3	1.374 m	92.4 g	967
3	1 N	0.0107 mm	93.5	1.1242 m	75.6 g	1237
4	1 N	0.0148 mm	67.6	0.8162 m	54.9 g	1232
5	1 N	0.0036 mm	277.8	0.9243 m	62.1 g	4471

Table 4: Force of Buckling - 5 N Load

Design	Member Length	Buckling Force	Maximum Force Predicted	Factor of Safety
1	30 cm	52.5 N	30.4 N	1.72
2	5 cm	1891 N	25 N	75.6
	7.07 cm	946 N	7.07 N	133.7
3	7.07 cm	946 N	7.07 N	133
	10 cm	472 N	25 N	18.9
4	15 cm	210 N	15 N	14
	15.8 cm	189 N	15.8 N	12
5	10 cm	472 N	15 N	31.5
	14 cm	241 N	7.071 N	34.1
	20 cm	118 N	5 N	23.6

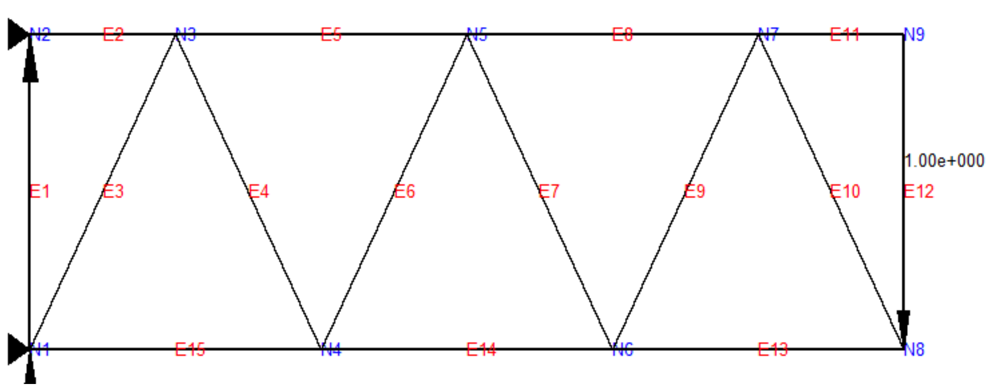

Figure 2: Design Three

Table 5: Design Three - Indeterminate Structures Analysis

Element	Force (N)	Element Deflection (m)
1	1	6.578e-8
2	6	3.947e-7
3	1.4142	1.315e-7
4	1.4142	1.315e-7
5	4	5.2627e-7
6	1.4142	1.315e-7
7	1.4142	1.315e-7
8	2	2.63e-7
9	1.4142	1.315e-7
10	1.4142	1.315e-7
11	0	0
12	0	0
13	1	1.315e-7
14	3	3.947e-7
15	5	6.578e-7

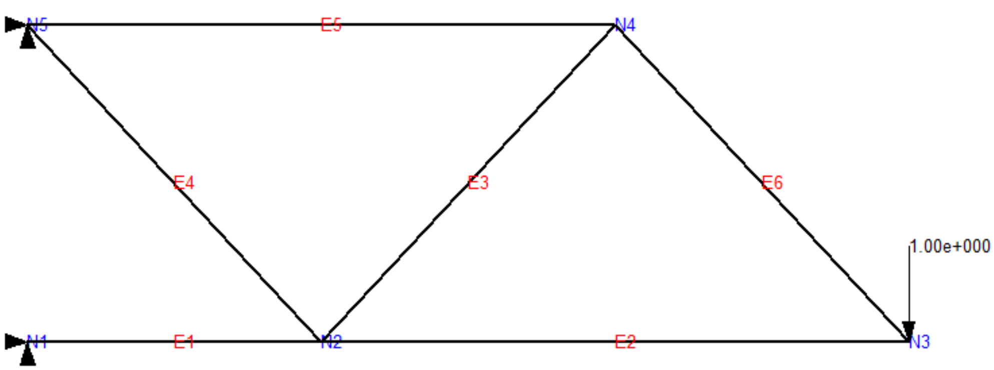

Figure 3: Design Five

Table 6: Design Five - Indeterminate Structures Analysis

Element	Force (N)	Element Deflection (m)
1	-3	3.947e-7
2	-1	2.63e-7
3	-1.4142	2.60e-7
4	1.41421	2.63e-7
5	5	5.26e-7
6	1.41421	2.60e-7

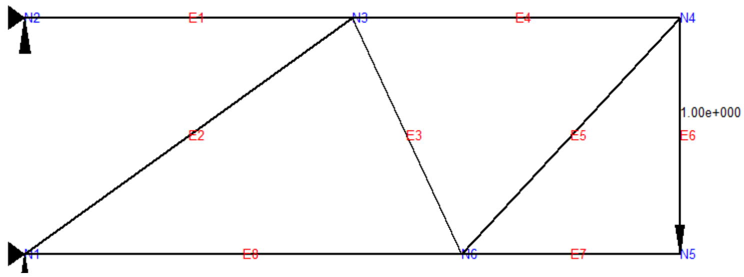

Figure 4: Design Six

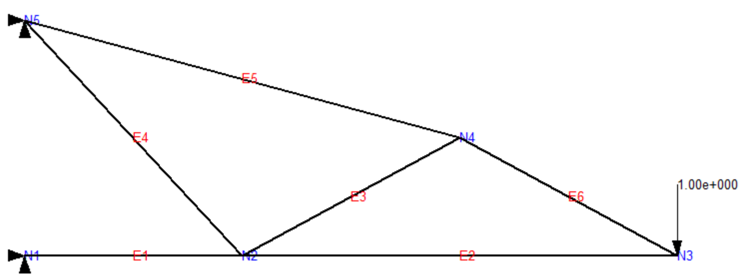

Figure 5: Design Seven

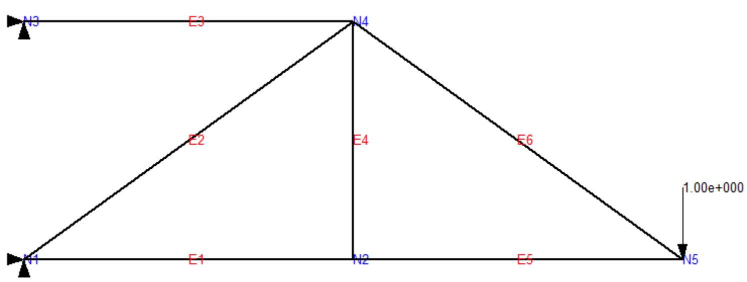

Figure 6: Design Eight (Height of 10 cm)

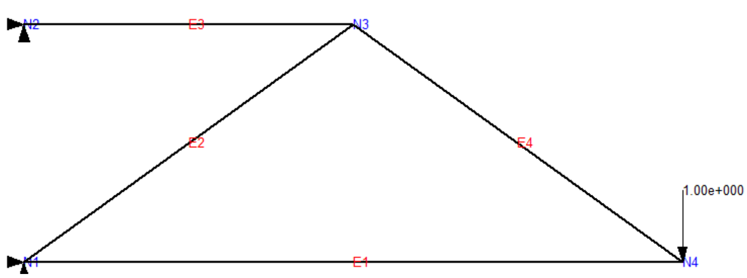

Figure 7: Design Nine

3D Structures

Although the results from 2D behavior resemble closely the 3D behaivor, 2D results are only approximation. Several assumptions are made to simplify the calculations such as no bending, all joints are pinned and forces act on the same plane. The behavior of 3D is not exactly as predicted 2D behavior. However, 2D will give a good indication (approximation) of the magnitudes of the forces and deflection of each member in 3D design. A 2D analysis will also likely provide a reliable indication of the most efficient 3D structure

FEM and Indeterminate Structures

The finite element analysis was performed on structure 3, which differed from our values obtained by indeterminate analysis by a factor of 2. Accounting for this, our values are within 20%, which is within an acceptable range.

Additional Methods

We plan to use 2-D finite element outcomes to tweak our design for optimization as well as indeterminate truss calculations to confirm our FEA results. In addition, since our final design will be in 3-D, we will consider using SolidWorks. The advantage to this method is that it allows us to visualize different possible 3-D structures and also apply rudimentary finite element analysis to the completed design.

Improving Efficiency

By the definition of efficiency (stiffness/weight), the two ways to improve efficiency are either to increase the stiffness or reduce the weight. We discovered that by increasing the height of the truss, to a maximum of 10 cm, we were able to increase the stiffness significantly for a variety of designs. On the other hand, by choosing designs with fewer members, we were able to reduce the overall length of brass rod used and minimize weight.

1.4 Conclusion

It appears the fifth design given proves the best efficiency and has a large factor of safety in all compressive members. Additional examination of this design will be performed and a 3D model built to validate 2D calculations and assumptions. More accurate constraints for mounting will also be considered. Overall, the feature which was found to contribute most to structure efficiency was height.

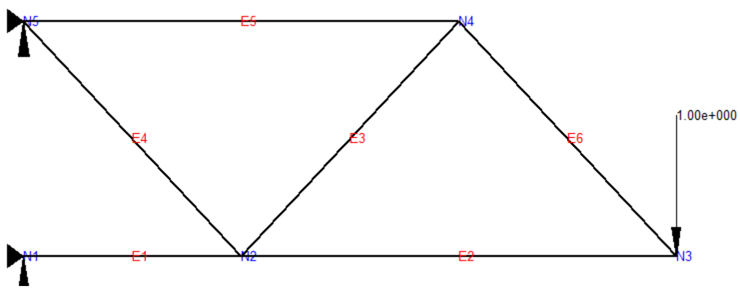

Figure 8: Design Ten (Height of 5 cm)

Table 7: Stiffness and Efficiency - New Designs (96 GPa)

Design	Stiffness			Efficiency		
	Applied Force	Deflection	Stiffness	Material Length	Weight	Efficiency
6	1 N	0.0133 mm	75.2	0.991 m	66.6 g	1129
7	1 N	0.0045 mm	222.7	0.871 m	58.6 g	3803
8	1 N	0.0017 mm	602.8	0.911 m	61.2 g	9848
9	1 N	0.0042 mm	237.7	0.811 m	54.5 g	4364
10	1 N	0.0122 mm	82.0	0.8354 m	56.2 g	1460

2 Brass Soldering

This section of the lab outlines the best practices and a standard operating procedure to join brass rods using lead solder.

2.1 Safety Precautions

The following safety precautions should be followed at all times.

1. Wear safety glasses when soldering and cutting rod.
2. Wear gloves while soldering.
3. Wash hands after soldering (Lead solder is used).
4. Use fume hood when soldering.
5. Ensure all equipment is powered off when not in use
6. Keep area around workstation clean of unnecessary tools and scrap material

2.2 Standard Operating Procedure

The following standard operating procedure was found to produce the best quality joints.

1. Review safety precautions and ensure all guidelines are followed at each stage of the joining process.
2. Cut and grind the ends of the brass rods such that they contact fully for the desired angle for which they will be joined.
3. Place protective metal plate on table.
4. Clamp brass rods with joints to be soldered to the plate but ensure the joint is over the edge of the table in the desired position. Ensure the clamps are stiff and that the rods are unlikely to move during the soldering procedure.
5. Heat joint with soldering iron - apply only enough solder to the tip of the iron to ensure sufficient heat transfer to the joint.
6. Apply solder to joint, not to the tip of soldering iron.
7. Continue to heat the joint and apply solder until all sides are covered.
8. Remove the soldering iron and solder and allow joint to cool.
9. Visually inspect and gently test joint by hand to ensure sufficient strength.
10. If the joint is critical and additional strength is required, solder a cross brace to the joint (see figure 9).

2.3 Joint Analysis

Each joint created was qualitatively tested by hand until failure occurred. Three important joint characteristics important to the final truss design were considered; flexibility, fragility, and failure mode. Joints were found to have little flexibility. Any bending observed was seen to occur in the brass members rather than the joint itself. Although it is difficult to state conclusively with so few samples, joints appeared to become more fragile after cyclic loading. Joint strength was also seen to be highly dependent on the contact area between the solder and bras rods. Increasing the amount of solder generally increased strength. The most likely failure mode was seen to be failure in bending. It was very difficult to pull the joints apart and cause then to fail by hand without bending them. This was particularly true for joints with large amounts of solder.

2.4 Conclusion

From the first part of the lab, it is known the truss should not experience significant deformation. Since joints will be exposed to little bending and appeared quite strong in tension and compression, any well constructed joint is unlikely to fail. Reinforcing joints with a cross member (as seen in figure 9) added significant strength and should be done for critical joints.

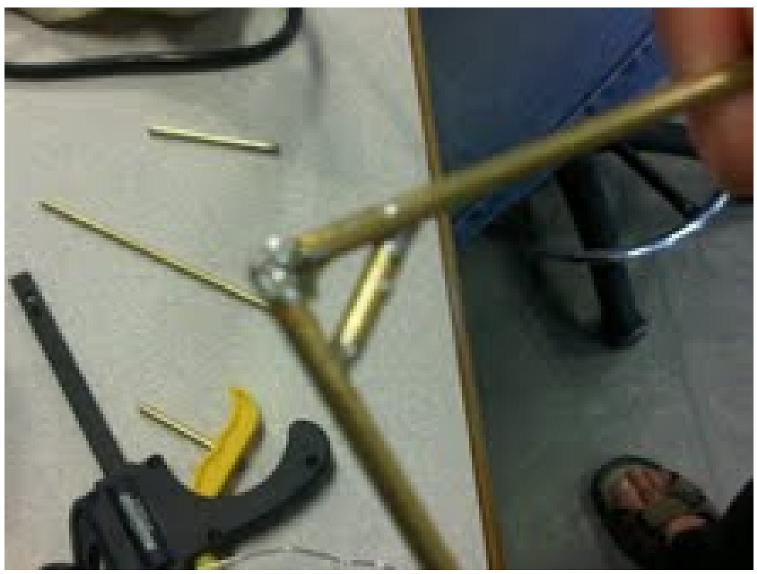

Figure 9: Joint Brace - Provides Significantly Improved Strength