EK301 Final Design Report

Prof. Albro

Section A2

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4th December 2020 at 11:00 pm

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(I) Introduction

When designing our final truss, we focused on a combination of maximizing the load and the load-to-cost ratio. Increasing the load to cost ratio means that the truss is more cost-effective for the amount of force it can withstand. Just increasing the cost or increasing the load individually neglects another important aspect of the design. We took a previous model we created from our preliminary design report (Design 3) which was our best design in terms of following all the specifications from section 1.2 while also withstanding the nominal live load of 32 oz. From this initial model, kept adding modifications to purposefully focus on maximizing the load until we designed a truss where it surpasses our initial design.

(II) Procedure

When designing trusses for the preliminary design report, we solely tried to build trusses that followed the specification from section 1.2. Together on zoom, we hand-drew some design ideas and input them into our code, not thinking about the maximization of the load and the load-to-cost ratio. There was no rhyme or reason to each of our designs, which explains why only one of our designs was withstanding the nominal live load of 32 oz.

This time, we wanted to be more meticulous about our modifications. We came up with an idea that we should try and mimic the natural world around us, specifically hemispheres. Thus all modifications made to design 3 were an attempt to create a more hemispheres-like geometry. Every time we made modifications, we ran the code and checked the value of the load and the load-to-cost ratio. We kept making modifications until we surpassed our goal of 100oz as the load. The following tables show our initial design before any modifications.

Figure 1: Diagram for Design 3

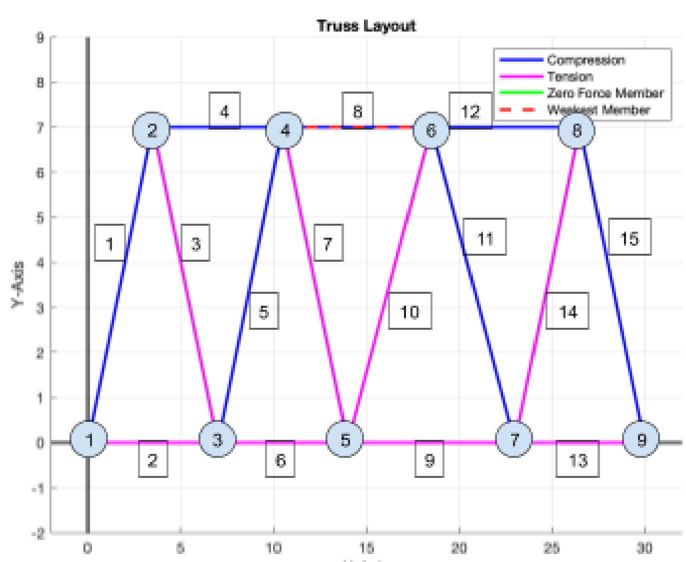


Figure 2: MATLAB Output for Design 3

```
>> InputTrussInfoCode
Do you want to (1) - Input a File // (2) - Input Information Directly: 1
Please enter the file name (filename.mat): TrussDesign3_PrinjaliRushanYumin_A2.mat

Please enter the units being used: (1) - oz/inches // (2) - N/m: 1
//EK301, Section A2, Group #: Prinjali K, Rushan M, Yumin W, 30/10/2020.

Load: 32.00

Member forces in Ounces:
m1: 19.081 (C)
m2: 8.533 (T)
m3: 19.081 (T)
m4: 17.067 (C)
m5: 19.081 (C)
m6: 25.600 (T)
m7: 19.081 (T)
m8: 34.133 (C)
m9: 24.533 (T)
m10: 17.753 (T)
m11: 17.753 (C)
m12: 14.933 (C)
m13: 7.467 (T)
m14: 16.696 (T)
m15: 16.696 (C)

Reaction Forces in Ounces:
Sx1: 0.000
Sy1: 17.067
Sy2: 14.933

Cost of Truss: $206.60
Maximum Load: 43.215 ± 20.00
Theoretical Max Load/Cost Ratio in oz/$: 0.209172

Member Forces Under Max Load in Ounces:
m1: 25.768 (C)
m2: 11.524 (T)
m3: 25.768 (T)
m4: 23.048 (C)
m5: 25.768 (C)
m6: 34.572 (T)
m7: 25.768 (T)
m8: 46.096 (C)
m9: 33.132 (T)
m10: 23.975 (T)
m11: 23.975 (C)
m12: 20.167 (C)
m13: 10.084 (T)
m14: 22.547 (T)
m15: 22.547 (C)

Weakest Member: Member 8
```

Member	Length(in)	Tension(1) / Compression(-1)	Buckling_Strength(oz)	Max_Load_Forces(oz)	Uncertainty(oz)
1	7.8262	-1	48.026	25.768	20
2	7	1	0	11.524	20
3	7.8262	1	0	25.768	20
4	7	-1	59.155	23.048	20
5	7.8262	-1	48.026	25.768	20
6	7	1	0	34.572	20
7	7.8262	1	0	25.768	20
8	8	-1	46.096	46.096	20
9	9	1	0	33.132	20
10	8.3217	1	0	23.975	20
11	8.3217	-1	42.824	23.975	20
12	8	-1	46.096	20.167	20
13	7	1	0	10.084	20
14	7.8262	1	0	22.547	20
15	7.8262	-1	48.026	22.547	20

```
Do You Want to Export the Table to Excel? Y or N: Y
Please enter the file name (filename.xlsx): TrussDesigns_PrinjaliRushanYumin_A2.xlsx
Please enter the sheet name (sheetname): TrussDesign3
```

(III) Analysis

There have been a few additional equations we have added to our code that was not present during the preliminary design report. Due to the model validation study, we added equations to calculate the dead load tension and the C_m:

$$C_m = T_m / W_l \qquad \text{Eq. (1)}$$

Where, T_m *= Tension of Member (m)*

W_l *= Weight of Live Load*

$$T_m^{dead} = T_m^{total} + W_l \times C_m \qquad \text{Eq. (2)}$$

Where, T_m *= Tension of Member (m)*

W_l *= Weight of Live Load*

Besides that, we did not make any other changes to our analysis. To account for the uncertainty, we did not use any specific formulas. Rather we kept our uncertainty at a constant of ±20oz as given by the GSTs buckling fit equation analysis.

(VI) Results

Figure X below shows the MATLAB output code when running the .mat file for Truss Design 14.

Figure 3: MATLAB Output Code for Truss Design 14

```
>> InputTrussInfoCode
Do you want to (1) - Input a File // (2) - Input Information Directly: 1
Please enter the file name (filename.mat): TrussDesign14_PrinjaliRushanYumin_A2.mat

Please enter the units being used: (1) - oz/inches // (2) - N/m: 1

Do You Have a Value for Weight Per Unit Length? Y or N: Y
Please Enter the Variable File for Weight Per Unit Length: wpl_acrylic


//EK301, Section A2, Group #: Prinjali K, Rushan M, Yumin W, 30/10/2020.

Load: 32.00

Member forces in Ounces:
m1: 20.833 (C)
m2: 11.947 (T)
m3: 4.014 (T)
m4: 19.821 (C)
m5: 3.309 (C)
m6: 23.461 (C)
m7: 16.046 (T)
m8: 14.616 (T)
m9: 6.988 (T)
m10: 23.457 (C)
m11: 13.588 (T)
m12: 15.887 (T)
m13: 16.509 (C)
m14: 6.395 (C)
m15: 7.020 (T)
m16: 18.228 (C)
m17: 10.453 (T)

Reaction Forces in Ounces:
Sx1: 0.000
Sy1: 17.067
Sy2: 14.933

Cost of Truss: $232.86
Maximum Load: 105.415 ± 20.00
Theoretical Max Load/Cost Ratio in oz/$: 0.453
Nominal Load (32oz)/Cost Ratio in oz/$: 0.137

Member Forces Under Max Load in Ounces:
m1: 68.627 (C)
m2: 39.355 (T)
m3: 13.222 (T)
m4: 65.294 (C)
m5: 10.899 (C)
m6: 77.287 (C)
m7: 52.858 (T)
m8: 48.147 (T)
m9: 23.022 (T)
m10: 77.272 (C)
m11: 44.762 (T)
m12: 52.334 (T)
m13: 54.385 (C)
m14: 21.065 (C)
m15: 23.126 (T)
m16: 60.049 (C)
m17: 34.436 (T)

Weakest Member: Member 10
```

Member	Length(in)	Tension(1) / Compression(-1)	Buckling Strength(oz)	Max Load Forces(oz)	Uncertainty(oz)	Dead Load Tension(oz)	Cm	Internal Max Load Force - Dead Load Included
1	6.1033	-1	76.419	68.627	20	0.48826	-0.65102	-68.139
2	7	1	0	39.355	20	0.56	0.37333	39.915
3	6.1033	1	0	13.222	20	0.48826	0.12543	13.71
4	6.3295	-1	71.397	65.294	20	0.50636	-0.6194	-64.788
5	9.4585	-1	33.713	10.899	20	0.75668	-0.10339	-10.142
6	6.0177	-1	78.462	77.287	20	0.48141	-0.73317	-76.805
7	11.125	1	0	52.858	20	0.88999	0.50143	53.748
8	7	1	0	48.147	20	0.56	0.45674	48.707
9	10.3	1	0	23.022	20	0.824	0.21839	23.846
10	6.0671	-1	77.272	77.272	20	0.48537	-0.73303	-76.787
11	11.152	1	0	44.762	20	0.89213	0.42463	45.654
12	9	1	0	52.334	20	0.72	0.49645	53.054
13	7.2823	-1	54.943	54.385	20	0.58259	-0.51592	-53.803
14	9.8671	-1	31.152	21.065	20	0.78937	-0.19983	-20.276
15	6.3382	1	0	23.126	20	0.50705	0.21938	23.633
16	6.7136	-1	63.956	60.049	20	0.53709	-0.56964	-59.511
17	7	1	0	34.436	20	0.56	0.32667	34.996

```
Do You Want to Export the Table to Excel? Y or N: Y
Please enter the file name (filename.xlsx): TrussDesign14_TableOutput.xlsx
Please enter the sheet name (sheetname): TrussDesign14
```

The table seen in **Figure 3** can also be accessed separately from this link as well:
https://drive.google.com/file/d/1BcCD87rCwMlOY7S09j4Q37qRQSRjV39o/view?usp=sharing

Figure 4: Diagram for Truss Design 14

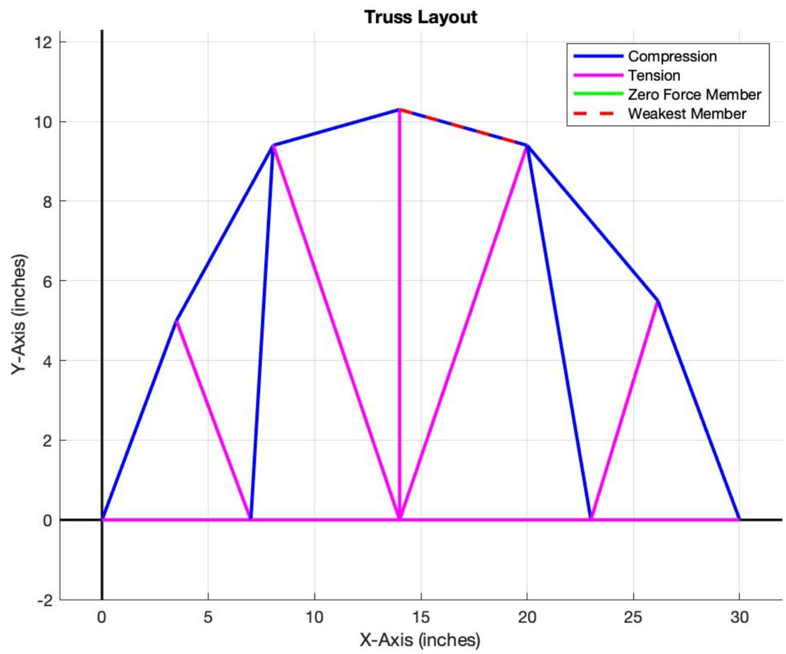
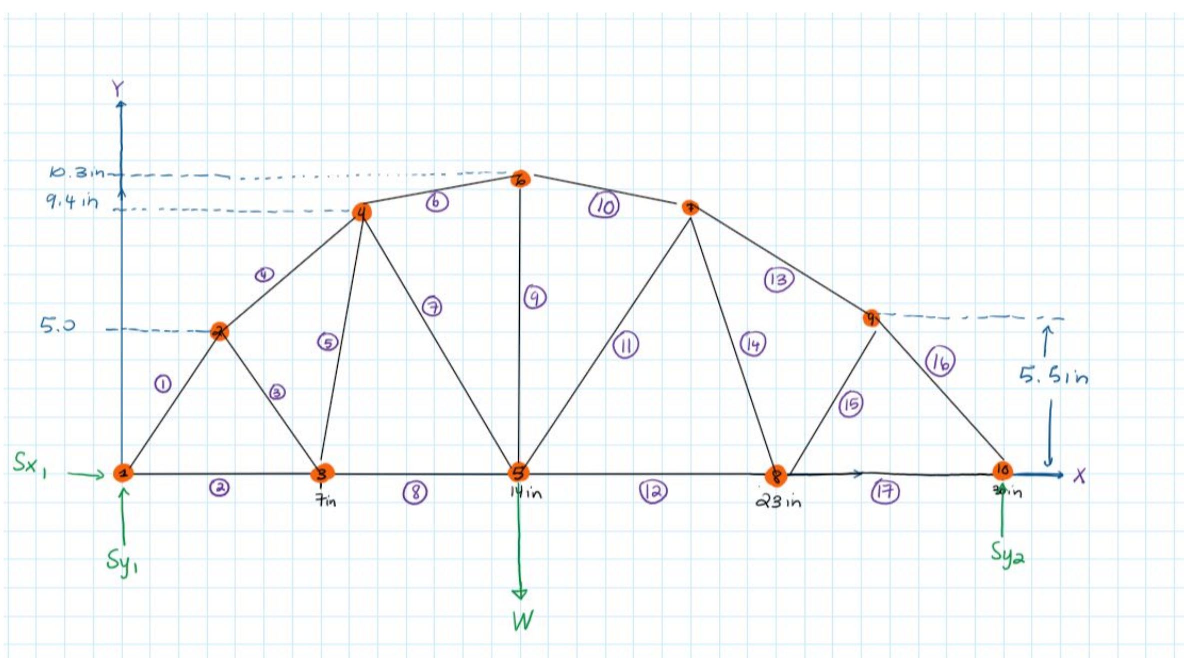


Figure 5: Truss Design 14 Free Body Diagram (With Member Numbers)



(V) Discussion

When attempting to maximize the load and the load/cost ratio, we tried several arrangements of different combinations of triangles, varying the height and number of spaces between the members. We had previously tested a design that resembles our current design, with promising results, and hoped to improve the design to be able to withstand a larger load. The previous design consisted of a simple trapezoidal form where all of the upper and lower members were horizontal. We found that increasing the height of the truss caused the load to be distributed at a smaller angle, thus reducing the amount of strain on the inner members. In theory, if the truss could be represented by a single bar, the truss can withstand a larger amount of force. We wanted to determine a design that would distribute this new force more evenly than a rectangular form would. Using the concepts of nature around us, we wanted to incorporate a circular or spherical design since a sphere is the most structurally stable shape in nature. A force acting on a circular shape is distributed within its body, thus decreasing the amount of strain on each individual member. This phenomenon is evident in molecular structures, whereby it can be observed in nature that molecules will form a conformation that most evenly distributes strain, namely a circular or ring shape. Although a complete circle cannot be formed in a truss, we can attempt to replicate this distribution of force through a hemisphere form by utilizing short members on the upper edge of the truss.

After attempting to form an overall triangular shape, we found that attempting to create a concave form, resembling a curved surface increased the maximum load as well as the load/cost ratio. This could be accomplished by shortening the two outer vertical members and increasing the length of the two inner vertical members. We could create a rounder shape by analysis of the weakest member and attempting to shorten the member until we reached the lower limit of the length. Initially, the weakest member would switch between the members, until we had shortened all of the upper-level members. From our previous trials, we found that the ability of a triangular truss to distribute the force evenly on both sides may help optimize our design. In order to apply this concept, we created a more rounded form by adding a member in the center, allowing the truss to have the highest point, similar to a triangular truss. We found that the individual series of changes increased the max load and load/cost ratio. We changed these new parameters until we reached the limits of the design constraints. We believe that our design optimizes the rounded truss shape and triangular shape in one design.

(VI) Appendix

A. Hartford Civic Center Arena Roof Collapse Minutes

Date: December 3, 2020
Start Time: 20:25 EST

I. Participants:

- Prinjali Kalyan
- Yumin Wei
- Rushan Manek

II. Agenda:

- Discuss overall reactions to the article
- Identify major problems
- Important Points
- What we learned from the case study and how it will apply to the design of our own truss

III. Discussion

Overall Reactions (suggested by Yumin)

- *Yumin:* We can start by discussing our overall reactions to the article. My opinion is that the entire situation could have been avoided if the people in charge asked more questions throughout the process instead of being overconfident in their answers.
- *Rushan*: One more thing is that they should have put an increased focus on safety instead of cost and should have listened to their employees and other collaborators when they raised concerns about the stability of the frame.
- *Prinjali*: Another aspect of their failure is that they did not listen to the concerns of citizens that questioned the stability of the frame before it was completed. They were lucky that there were no people in the arena when it fell.
- *Rushan:* I found it interesting that the structural consultant that was hired by the architect's insurance company said that the cause for the failure was completely different than what everyone else pointed out. I think this is because they are trying to shift the blame away from the architects because they would have to pay for the faults of the architects.

Major Problems in connection with Code of Ethics of Engineers (suggested by Prinjali)

- *Prinjali*: Throughout the design process, they opted for more cost-effective materials and designs rather than considering the actual stability of the design.
- *Yumin:* I feel like we are getting into the ethical grounds of the case study. We can start discussing the Code of Ethics of Engineers. I think the number one rule they broke was that their number one priority was to save money rather than save or protect lives.
- *Rushan:* They put the value on money as opposed to their user lives and safety which goes against the number 1 Fundamental Canon as stated in the Code of Ethics for Engineers.
- *Yumin*: Another way they detracted from the Code of Ethics was their lack of communication between all of the parties involved because it was divided into five subcontracts coordinated by one construction manager. Because of the lack of communication there were a lot of technical errors rather than computation eros that could have been avoided.
- *Prinjali*: It seems as though they did not consider all of the possible causes of error, indicating that they were not very thorough in their design process and decision making process. In our truss design, we should ensure that we consider all possible errors for our design. One source of error is relying on the predictions by computer programs rather than performing experiments ourselves.
- *Rushan*: A margin of error should be applied when comparing computer analysis to real-life applications.
- *Yumin:* At the same time, I disagree with that point because if the computer told them there was no error or a large error, as good engineers they should have been able to distinguish what is reality and what isn't by being involved in the building process. A good quote from the article was that, "[c]omputers, however, are only as good as their programmer and tend to offer engineers a false sense of security". If the computer program is not taking all of the possible sources of error, then the simulation will not work in real life. The computer program is the best case scenario if everything goes right. But in this case everything went wrong.
- *Prinjali*: They did not stick to their original design plans and a lot of the steps were changed along the way. This proves that the intermediate steps of design and validation are equally important to building and testing.
- *Rushan*: Going back to ethics, it says that "if errors occur then the engineers must take responsibility for them", and the construction manager said that a structural engineer was too expensive and not needed and that "he would inspect the project himself". But when the collapse happened, he said that he was not responsible at all and that the error was a design error which would pinpoint the blame off himself and onto the architects.

- *Yumin:* I think we can start summarizing the most important points and then talk about how we can use these points to develop a truss in our own project.

Summary of Important Points (suggested by Rushan)

- *Prinjali:* Always stick to the Code of Ethics for Engineers, regardless of the scale of the project and especially when it could lead to the harm of others.
- *Yumin*: It is fine to use a computer program but you cannot depend solely on that data and you must account for all factors when programming.
- *Yumin*: Communication is vital to a successful engineering project. Even if you do not want to, you have to talk to each other to know what everyone is doing.
- *Rushan:* It is important to accept responsibility if any design errors occur. The primary objective of an engineer is to ensure safety of the product's users.

Application to Our Truss Project (suggested by Yumin)

- *Prinjali*: Establishing checkpoints within the timeline of the project to ensure that everything is working correctly before moving on is an effective method to avoid errors and to be thorough.
- *Rushan*: Making sure to provide an uncertainty to whatever the computer analysis provides for example, if the analysis says that the truss can handle 40 ounces, assume that it will buckle at 35 ounces. Test to see if the truss can handle the additional 5 ounces.
- *Prinjali:* Testing with a prototype before actually building can help identify any cause of error.
- *Yumin:* Building a prototype will help keep everyone on the same page so there are no surprises or independent acts or changes to the design.
- *Rushan*: Make sure that all of your connections are good before adding the load.

IV. Conclusions and Action Items (suggested Prinjali)

- *Yumin:* After reading this article, I think we all learned from their mistakes and can apply it to our own project.
- *Prinjali*: This is a story that we can take onto future projects to keep in mind as Societal Engineers.
- *Rushan*: Let us not forget to add the minutes to our report.

End Time: 21:23 EST

B. MATLAB Code

- Copy of MATLAB code: https://drive.google.com/drive/folders/1wZ5zT3LE00bl4BO5PiVrysaREi2mPCml?usp=sharing

C. Truss Design 14 MATLAB File

- Copy of Truss Design 14 (.mat): https://drive.google.com/file/d/1sKEEZ0n9LGTOcTjExNeeIv21rlxEX_wg/view?usp=sharing