Final Design Report

Truss the Process: Sally Stronge, Vincent Brunn, Avyukta Srikrishna, Moataz Sayed

Professor Michael Albro: EK301 A4 Fall Semester

Introduction:

For our final truss design, we decided to prioritize maximizing both the maximum load and load-to-cost ratios to the best of our ability. With this in mind, we workshopped several designs and ultimately decided to prioritize supporting a maximum load, as with our combined reports, only one previous design met the requirements of sustaining the required 32 ounces and met all the truss design requirements. While it was able to hold a maximum theoretical load of 49.31 ounces and only cost $199.96, with this being the only truss that met our needs, we believed we had room for improvement.

Thus, during our final design phase, we prioritized redesigning our previous trusses and coming up with new designs that would maximize load but keep cost down. We were aiming for above 49.31 ounces and around $200-$240 for the cost, however, in the end, we did aim to maximize load. To ensure this, we decided to disregard the uncertainty to make sure we accurately calculated the strength of the truss.

Procedure:

During the formulation of new designs, no significant changes were made to our procedure. The greatest change we made was making the truss asymmetrical in order to meet the requirements set out by the EK301 staff. In some of our previous designs, we miscalculated the lengths of the bottom chord, which did not fulfill this requirement, so during the redesign phase we corrected this. Similar to before, we made sure to keep the members as short as possible–within the given range of 7-14in–for the shorter the length, the greater the buckling force. Lastly, we worked on maximizing our theoretical load. Although we had done this previously, we believed with our modifications, the theoretical loads would change so we took this into consideration. By using our code from the preliminary design report, we were able to quickly and efficiently test our new designs and ensure that our truss costs <$300 and holds at least 32 oz.

Although the process didn't change much from the preliminary design to the final design, we were able to take a more procedural approach as we had more experience. We split up the work among our team, where a couple of people made designs and compared, while the others ran the code. Again, we researched which trusses helped the highest maximum loads and used this as our base. We then started with figuring out the lengths of the members in the bottom chord as this was part of one of constraints: live load must be 14-15in away from the pin joint. We also tried to ensure most members remained in 7-8in lengths as this would have the highest buckling loads and would only decrease as they got longer. With all this in mind, we set out trying different designs, and seeing how they would perform.

Ultimately, the main differences from the preliminary design to the final design was just ensuring we met all the design requirements and maximized our theoretical load, while minimizing the cost. Overall, the redesign was easier than the original design as we had a smoother process and more experience. We easily made several new designs with similar structures, just different lengths, that significantly increased our theoretical load and load-to-cost predictions. By taking the extra time and care with the redesigns of our truss, as a team, we are ensuring our success by surpassing our minimum requirements even with the uncertainty of 1.54% taken into account. With more experience and iterations, we created one final design that best fits our needs.

Analysis:

In light of our preliminary design, which did not sufficiently meet the minimum strength requirement, we explored various new truss configurations, including right trapezoidal, Pratt, Howe, and castle-like shapes, in pursuit of a greater maximum load. Despite these efforts, the new designs often yielded lower or equivalent maximum loads, leading us to refine the original preliminary design instead of overhauling it completely.

Adjustments included modifying member lengths, the number of triangles, and the weight's position. Through these iterations, we observed key patterns that informed more effective design choices. Most notably, shorter member lengths consistently improved maximum load capacity, which tracks with the data from the buckling lab, as shorter lengths often led to better buckling resilience, within reason. Further, extending the placement of the weight to precisely 15 inches from the joint netted more favorable performance without having an effect on cost. Based on these insights, the final truss design incorporated as many 8-inch members as possible, with a single 9-inch beam to ensure the 32-inch span requirement, while still positioning the weight at the optimal distance of 15 inches from the joint. These new measures proved greatly effective, resulting in a multiple-fold increase in maximum load, while still managing to cut the cost down.

Uncertainty Analysis:

The method used to calculate the uncertainty in the truss failure load involves assessing the effect of member buckling strength variability on the overall truss performance. The critical member, which fails first under compression, determines the truss failure load. Each compression member's buckling strength is expressed as $P_{crit} = P_{nom} \pm U_{fit}$, where P_{nom} is the nominal strength and U_{fit} is the uncertainty due to material and measurement variability. To account for this uncertainty, three scenarios are evaluated: the nominal case (using P_{nom}), the strong case (using $P_{nom} + U_{fit}$), and the weak case (using $P_{nom} - U_{fit}$). The failure load $W_{failure}$ is then calculated for each case, with the uncertainty range (ΔW) defined as half the difference between the strong and weak failure loads. The members that were experiencing compressive forces were: HI, GH, FG, CH, BG and AF.

The data is represented in the table below:

Member	**Length (inches)**	**Nominal Buckling Load (oz)**	**Strong Case (oz)**	**Weak Case (oz)**
HI	8.000	46.85	48.33	45.37
GH	8.000	46.85	48.33	45.37
FG	7.000	61.26	62.75	59.78
CH	8.602	40.49	41.98	39.01
BG	7.616	51.72	53.20	50.23
AF	8.602	40.49	41.98	39.01

The uncertainty for $W_{failure}$ is calculated by taking the range of the strong case and the weak case. The calculation is highlighted below:

$$\Delta W = \frac{62.75 - 39.01}{2} = 11.87.$$

Hence the uncertainty for the failure load is 11.87oz.

Results:

Final Truss Design

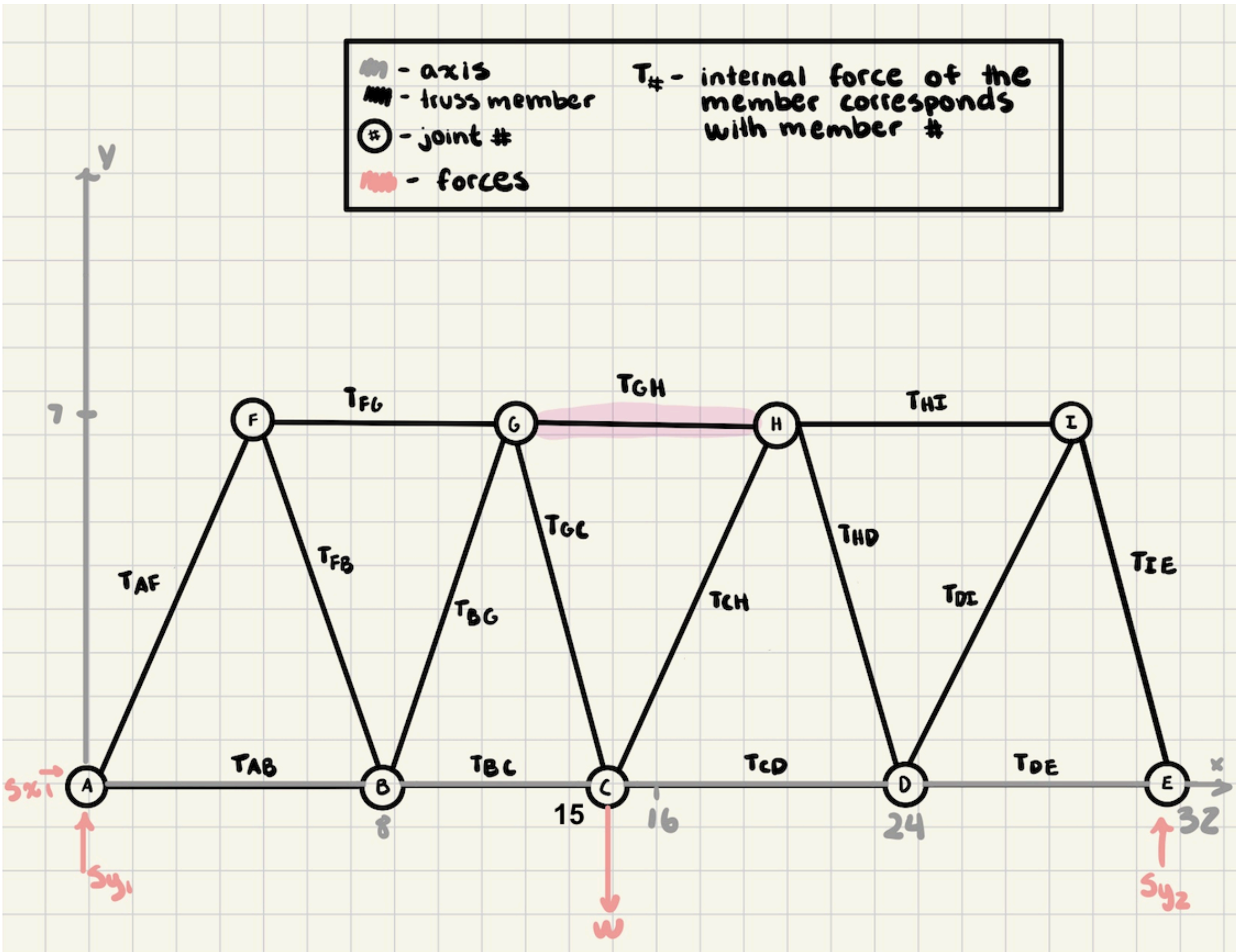

Figure 1: *The Final Truss Design* **-** *All joints and members are labeled and the reaction forces at the pin joint and roller joint are highlighted in a different color. The weight is shown at joint C (15 inches from the pin). The critical member, GH, is highlighted.*

Table 1: Key Performance Metrics of Final Truss Design

Member Label	Member Length (Inches)	Tension (T), Compression (C), or Zero Force Member (Z)	Buckling Strength (oz) with Uncertainty of ±1.54 oz	Magnitude of Force at Maximum Truss Load (oz)
AB	8	T	-	8.15

BC	7	T	-	22.4
CD	8	T	-	38.7
DE	9	Z	-	0
EI	8.602	Z	-	0
DI	8.602	T	-	94.4
HI	8	C	46.85	46.8
GH	8	C	46.85	30.6
FG	7	C	61.26	16.3
DH	8.602	T	-	16.4
CH	8.602	C	40.49	16.4
CG	8.602	T	-	16.4
BG	7.616	C	51.72	15.5
BF	8.602	T	-	16.4
AF	8.602	C	40.49	16.4

Table 2: Reaction Forces and Corresponding Magnitudes of Final Truss Design

Reaction Forces	**Force Magnitude (oz)**
Sx1	0
Sy1	14.3
Sy2	82.0

Table 3: Summary of Maximum Load, Truss Cost, and Load-to-Cost Ratio of Final Truss Design

Maximum Load (oz)	Truss Cost ($)	Load-to-Cost Ratio (oz/$)
96.24	209.59	0.45917

Discussion & Conclusion:

As previously stated, we worked on both optimizing our maximum theoretical load and load-to cost ratio. However, with this in mind, we decided maximizing our max theoretical load was our number one priority. When coming up with additional designs, we did some research and found out that Warren, Pratt, and Howe trusses seemed to hold the greatest loads. Through some trial and error, we made modifications to these types of trusses, and we found, in order to meet the criteria set out by the EK301 staff and optimize the maximum theoretical load, we needed the truss to be asymmetrical. Below is the final design (Design #1) as well as some of the initial truss designs from the Preliminary Design Report (Design #2 & #3).

Design #1:

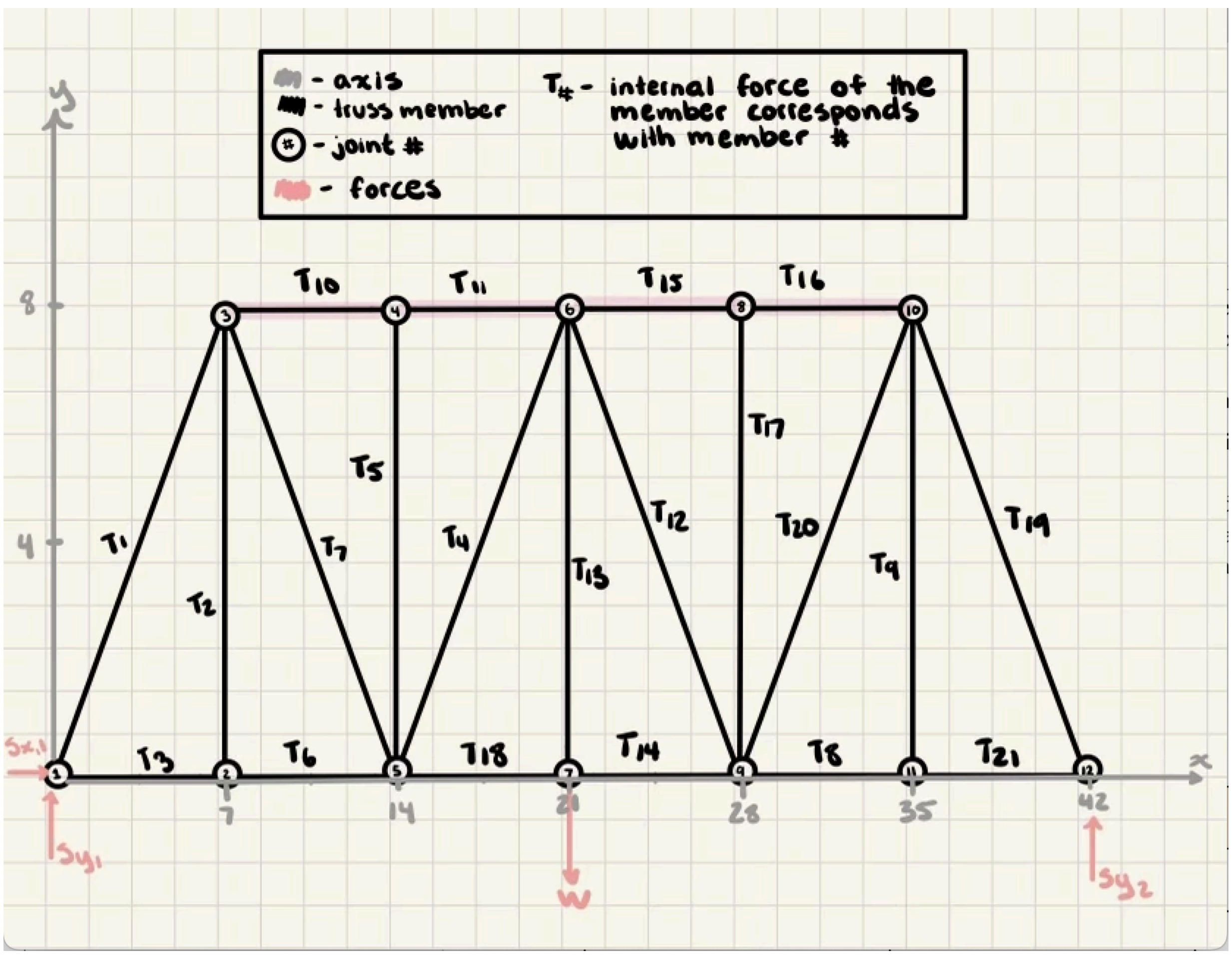

Figure 2: *First Preliminary Truss Design Candidate - All joints and members are labeled and the reaction forces at the pin joint and roller joint are highlighted in a different color. The weight is shown at joint 7 (21 inches from the pin). The critical member,* T_{10}, T_{11}, T_{15}, T_{16}, *are highlighted.*

Table 4: *Calculations from PDR Truss Design #1 that are useful for the improvement and enhancement of the design by a simple cost and maximum load calculation.*

Maximum Theoretical Load and Uncertainty	66.21 ± 1.54 oz (95%)
Total Truss Cost ($)	293.78
Load-To-Cost Ratio (oz/$)	0.81065

Design # 2:

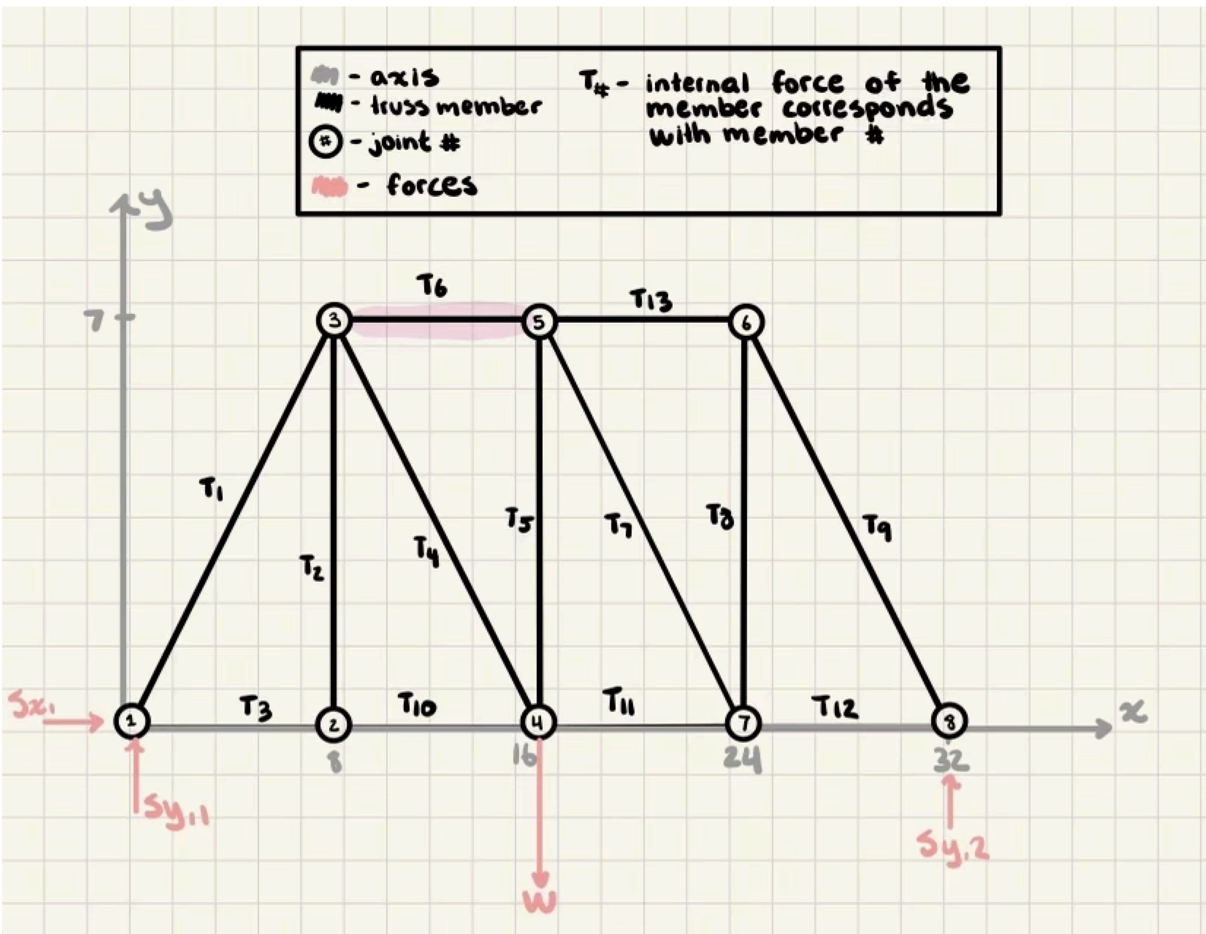

Figure 3: *Second Preliminary Truss Design Candidate* **-** *All joints and members are labeled and the reaction forces at the pin joint and roller joint are highlighted in a different color. The weight is shown at joint 4 (16 inches from the pin). The critical member, T_6, is highlighted.*

Table 5: *Calculations from PDR Truss Design #2 that are useful for the improvement and enhancement of the design by a simple cost and maximum load calculation.*

Maximum Theoretical Load and Uncertainty	49.31 ± 1.54 oz (95%)
Total Truss Cost ($)	$199.96
Load-To-Cost Ratio (oz/$)	1.1910

As shown above, our Preliminary truss designs followed the base designs of a Warren and Pratt truss. While these were not the final designs, it taught us a lot of how to optimize the truss. Due to the constraints, we had an uneven live load, which led us to create an asymmetrical truss. This discovery led us to optimize our design to the best of our ability, and we successfully did this as our final design is projected to hold a live load 96.24 oz and only costs around $209.59. This is a major improvement from our previous preliminary designs where the maximum theoretical load for 66.21 oz (PDR Truss Design #1) and 49.31 oz (PDR Truss Design #2), which cost $293.78 and $199.96 respectively. After realizing an asymmetrical design was best, our results immediately improved significantly.

The constraints were complicated at first but after some practice we were able to figure out the best way to distribute the weight. Some things we could do differently also occurred during the truss fabrication process. By cutting the acrylic strips by snapping them, we noticed that many of the edges were not straight which led to gapping in the joints. Because of this gapping in the joints, it caused us to use more tap to compensate for this weakness which is not ideal. Due to this human error, this will cause imprecision in our predicted calculations.

If we were to recreate our truss, we would like to precisely cut our acrylic strips using a tool such as a laser cutter that would ensure our acrylic strip lengths were exact as well as even. At the very least, we could get sandpaper or precision cutters for more accurate measurements. This would ensure that our predicted calculations would more accurately match our actual truss performance. Ultimately, if we had more time, we would explore more truss designs, such as going upwards or experimenting with different lengths, which could potentially improve our maximum theoretical loads.

Appendix:

A. Meeting Minutes of the Team Discussion Concerning the Hartford Roof Collapse

Hartford Roof Collapse Discussion Meeting
December 5, 2024
Meeting Time: 5:30pm

Attendees: Vincent Brunn, Avyukta Srikrishna, Sally Stronge, Moataz Sayed
Chair: Avyukta Srikrishna
Recorder: Sally Stronge

Agenda:

- Discuss the use of computer programs in analysis predictions and designs
- Discuss/define an appropriate safety factor that would be used on our truss if it were to be used in an event where human life is at risk and calculate the max theoretical load and report it
- Discuss and consider the variability in our design, material, construction, etc, in which might have an effect on the max theoretical load
- Refer and review the Fundamental Canon No.1 from the Code of Ethics of Engineers, National Society of Professional Engineers, 2018: "Engineers shall hold paramount the safety, health, and welfare of the public."
- Debate discrepancies between the materials, construction, and the final versus initial design of the roof

Meeting Notes:

1. We noticed that the engineers trusted the computer analysis way too much to verify the safety of the building without double checking, especially as these were money-saving innovations that did not follow a typical design.
2. We brought up the Code of Ethics of Engineers, focusing on the quote, "Engineers shall hold paramount the safety, health, and welfare of the public." We discussed that the engineers failed to uphold this ethical standard by prioritizing minimal cost over human safety.
3. We also noticed and discussed how the collapse was not an unforeseen circumstance. In fact, the engineers were made aware of their calculator errors twice and still made no effort to combat this error. It even came to the point where citizens of the error could visibly see the "large downward deflection," and still the engineers made no effort to fix their mistake and even took it a step further by assuring everyone it was okay.
4. We also observed that there were discrepancies in not only the calculations, but also the materials used, which likewise, impacted the integrity of the roof: some of the steel did not meet specifications, misplaced diagonal members, etc.
5. It also should be noted that while building and design were concerns, there were also procedural concerns where there were so many subcontractors that it led to miscommunication and confusion through out the entire project. This was to the extent that no one person understood the entirety of the project thus allowing for small errors to go unnoticed.

Meeting Adjourned: 7:00pm