EK301 Final Design Report

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Group Name: Tacoma Narrows Bridge

Section A2 - Professor Joseph Scott Bunch

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Introduction

The motivation and approach of the final truss design come from the Baltimore truss design. The focus of the design is to build a truss that can withstand the minimum load requirement in the specifications. The goal of achieving a high load-to-cost ratio was another consideration when designing the truss. While the uncertainty factor is important, the process when designing the truss ignored the uncertainty factor and focused more on achieving a high theoretical maximum load.

Procedure

For the design procedure, we have not made any changes since the preliminary design report, so our procedure is unchanged. We did not make any changes because all of our calculations were correct when analyzing multiple different truss designs using the program we developed in MATLAB as described in the preliminary design report.

Analysis

Since the preliminary design report, we have added uncertainty from the buckling data to our MATLAB code in Figure 3 as shown in the Appendix. Primarily, adding uncertainty to the buckling calculation by adding Weak case, Strong case, and Nominal case which considers the +/- uncertainty case shown below in Equation 1. Calculating three separate W_failure values creates a range based on the U_fit of the buckling lab. Due to this new uncertainty, we also found other members within this strong to weak range that may buckle first given the uncertainty. In our analysis of this truss, we found no members within the buckling U_fit range. In our new analysis, we found the next member to theoretically buckle is member 12 but it is not within the uncertainty range so we do not expect it to buckle.

For our final truss design, we did not make any changes to the truss that we will be using. Using the following equation below, we calculated the force that a member of our truss will buckle at as well as the uncertainty range.

Equation 1: $$F = 3054.789 \bullet L^{-2.009} \pm 1.36oz$$

Results

For our final truss design, we chose the first truss design from the preliminary lab report as shown in Figure 1 below. From the MATLAB calculations shown in Figure 2 in the appendix, the theoretical maximum load of our truss for the nominal case is 49.13 oz. Member 1 is the critical member to fail at an internal force of 33.641 oz as shown in Table 1 below. The total cost of our truss ended up being \$208.92 and has a maximum load-to-cost ratio of \$0.2351 $\frac{oz}{\$}$. The load that will be applied onto the truss is at joint 3 as shown in Figure 1 below, where the blue members are in tension while the red members are in compression. For members in compression, the strength of each member will buckle with an uncertainty of $\pm$1.36 oz. For the strong case scenario, member 1 buckles will buckle at an applied load of 51.11 oz, and for the weak case scenario, member 1 buckles will buckle at an applied load of 47.14 oz.

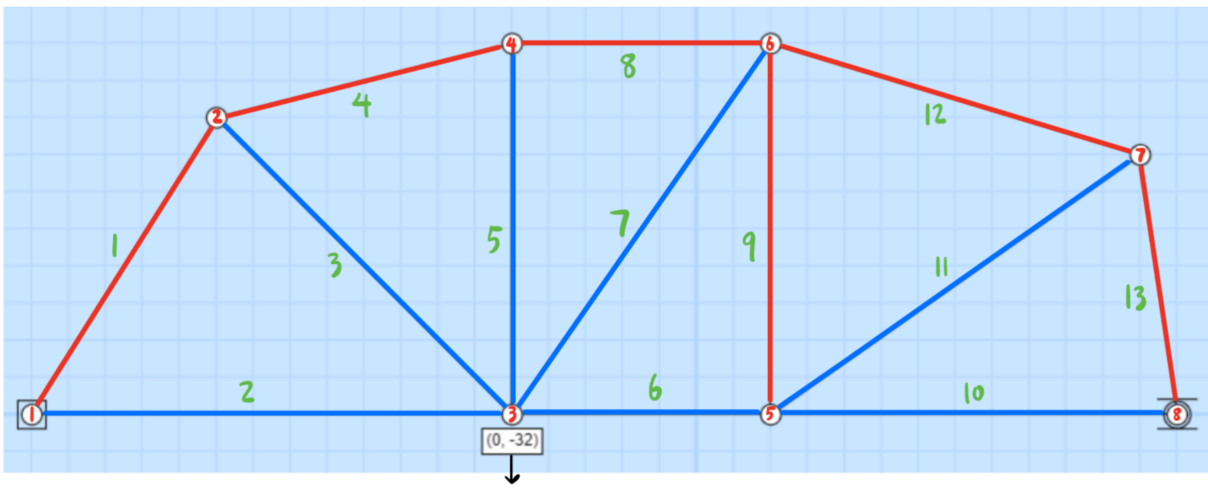

Figure 1: Final truss design, members and joints are labeled with load applied at joint 3, and members that are in tension are blue and members that are in compression are red.

Table 1: Data of our final truss design that includes internal forces in each member at nominal maximum load, whether each member is in tension or compression, and the expected strength of each member with the uncertainty given its length.

Member Number	Lengths (in)	Tension (T) or Compression (C)	Buckle Strength (oz) based on Member Length and Uncertainty	Internal Forces at Nominal Maximum Load = 49.13oz
1	9.434	C	$33.637 \pm 1.36oz$	33.641
2	13	T	-	17.829
3	11.314	T	-	27.232

4	8.246	C	$44.081 \pm 1.36oz$	38.227
5	10	T	-	9.271
6	7	T	-	22.663
7	12.207	T	-	25.149
8	7	C	$61.260 \pm 1.36oz$	37.085
9	10	C	$29.921 \pm 1.36oz$	13.804
10	11	T	-	2.943
11	12.207	T	-	24.071
12	10.44	C	$27.442 \pm 1.36oz$	23.661
13	7.071	C	$60.031 \pm 1.36oz$	20.812

Discussion & Conclusion

We first began with a basic Pratt truss design to get an idea of a baseline on how a truss should perform. One of the biggest influences on our design was the restrictions imposed on our group. The specifications imposed two important limitations on our design, there can't be a node between the pin node and the load node. The other restriction was that members have to at least be 7 inches in length so we can't split apart weak members to give them more support without going over the budget.

Our design process was iterative. We would build the simulation of the Pratt truss and slowly add more load until the buckled from the load. Since our simulation was accurate, we were able to pinpoint the weak member and come up with solutions that could improve the truss. We relied on trial and error and research to find that a Baltimore truss design was crucial in expanding the strength of the bridge. There were constant weak points that we had to address. The first was the top members that would break under compression. The easiest way to solve this problem was to increase the height of the bridge. The downside to increasing the height is that it exponentially increased costs and made any diagonal members break under compression. By implementing the Baltimore truss design, we were able to overcome any issues with the support member and increase our limiting factor which was the pin nodes. The final design that we chose from the preliminary report was truss design 1 simply because it is easier to build. The theoretical maximum load was greater in the second truss design but the building process would be more difficult and any error when building it would decrease the maximum load by a lot.

The element of the project we would like to see change is the minimum length requirement. We believe that smaller members open up to more possible design choices. Having shorter members means more nodes that can appear throughout the bridge and we can split the members even further which should hopefully expand the capability of the truss bridge.

Appendix

Meeting minutes of the Hartford roof collapse discussion[1]

Date: 4/19/2024

Time: 8 pm - 9 pm

Location: Mugar Library in GSU

Chair Person: Kailan Pan

Recorder: James Conlon

Agenda

1. Discuss the "Hartford Civic Center Arena Roof Collapse," especially focusing on the use of computer programs in analysis and design
2. Determine an appropriate factor of safety for our truss if it were used in a case where human life is at risk
3. Report our conclusion

Task 1:

- Kai mentioned getting input from other people about the design to get different views from different people
- Austin mentioned building a smaller model of the truss allows testing of the truss, and ensures everything runs smoothly in our program.
- James added to Austin's point, saying that since the computer program will only calculate the data that was provided, we should rigorously test the truss with different methods such as different programs, different structures of the truss, etc.
- Kai further explained that loads at every joint and along the lengths of the members would need to be tested.
- Austin thinks that if there are any discrepancies between our computer predictions and the actual testing of the truss, we should immediately stop and address the problems that occurred.

Task 2:

When human lives are at risk, a high factor of safety needs to be warranted. According to the Engineering Toolbox[1], for structural components of a bridge, the factor of safety is from 5 to 7 times the operating load. For our bridge, we decided to use a factor of safety of 7. Our predicted theoretical maximum load for the nominal case is 49.13oz so we would report that our truss is safe to operate at a load of 7.02oz. Acrylic can be variable in terms of its strength compared to wood or metal so it was another reason for our choice of a high factor of safety.

Task 3:

In conclusion, it is extremely important to be extra cautious when building structures that put human life at risk. We need to do vigorous testing and set a high factor of safety, and the construction process should be analyzed very carefully to ensure that everything is built correctly and no safety concerns arise. While doing so, we must make sure that all of our requirements for the truss are met, such as the maximum load and the budget of our client.

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Members are within range: 13 <= 13

Critical Member: m1

m1 with length 9.434in will buckle at nominal force: 49.13 oz

Strong case scenario: 51.11 oz

Weak case scenario: 47.14 oz

Other members near critical failure of strong/weak with +/-1.36 oz error: (if any)

Applied Load: 32.000 oz

Member forces in oz

m1: 21.911 (C)

m2: 11.613 (T)

m3: 17.737 (T)

m4: 24.898 (C)

m5: 6.039 (T)

m6: 14.761 (T)

m7: 16.380 (T)

m8: 24.155 (C)

m9: 8.991 (C)

m10: 1.917 (T)

m11: 15.678 (T)

m12: 15.411 (C)

m13: 13.556 (C)

Reaction forces in oz:

Sx1: 0.00

Sy1: 18.58

Sy2: 13.42

Cost of truss: $208.92

Theoretical max load/cost ratio in oz/$: 0.2351

Figure 2: MATLAB calculation results for Final Truss Design.

```matlab
% This function finds and prints both critical member and MIN (nominal) value of all
the Wfailures among the members.
% therefore it is the max theoretical load that the truss can support before the
weakest member buckles.
% Added for final report: weak, nominal, strong uncertainty.
function [critical_member, W_failure_min, W_failure_strong, W_failure_weak] =
buckleCalc(Pcrit_nom, Rm, memberLens)
   error_margin = 1.36; % U_fit range
   Pcrit_strong = Pcrit_nom + error_margin;
   Pcrit_weak = Pcrit_nom - error_margin;
   % W_failure for each member
   Wfailure_nom = -Pcrit_nom ./ Rm;
   Wfailure_strong = -Pcrit_strong ./ Rm;
   Wfailure_weak = -Pcrit_weak ./ Rm;
   % ignore 0 force members (or positive ie tension) by setting value to inf
   Wfailure_nom(Rm >= 0) = Inf;
   Wfailure_strong(Rm >= 0) = Inf;
   Wfailure_weak(Rm >= 0) = Inf;
   % [min Wfailure value, index] of the critical member
   [W_failure_min, critical_member] = min(Wfailure_nom); %output nominal
   W_failure_strong = Wfailure_strong(critical_member);
   W_failure_weak = Wfailure_weak(critical_member);

   %printer
   fprintf('Critical Member: m%d\n',critical_member);
   fprintf('m%d with length %.3fin will buckle at nominal force: %.2f oz\n',
critical_member, memberLens(critical_member), W_failure_min);
   fprintf('strong force: %.2f oz, weak force: %.2f oz\n\n',  W_failure_strong,
W_failure_weak);
   % potential critical members considering the strong and weak forces
   fprintf('Other members near critical failure of strong/weak with +/-%.2f oz error:
(if any)\n', error_margin);
   lower_bound = W_failure_min - error_margin;
   upper_bound = W_failure_min + error_margin;

   for i = 1:length(Wfailure_nom)
       if i ~= critical_member && Wfailure_nom(i) <= upper_bound && Wfailure_nom(i) >=
lower_bound % exclude the critical member but include any other member within range
           fprintf('m%d: failure load (nom) = %.2f oz, length = %.3f in\n', i,
Wfailure_nom(i), memberLens(i));
       end
   end
end
```

Figure 3: Modified buckling calculation considering: Weak Case, Strong Case, and Nominal Case.

Works Cited

[1] - Engineeringtoolbox, Editor. “Factors of Safety - Fos.” *Engineering ToolBox*, 9 Apr. 2024, www.engineeringtoolbox.com/factors-safety-fos-d_1624.html.

[2] - EK301 Blackboard Manual for Final Report Design