BOSTON UNIVERSITY
College of Engineering

EK 301	Engineering Mechanics	Fall 2023

Truss Design Project
SECTIONS: **PRELIMINARY DESIGN**
draft dated November 1, 2023

Schedule:

Part 1: Buckling Lab	20%	Oct 27 2023; 11:00pm	*to Gradescope*
Part 2: Prelim Design Report	35%	Nov 17 2023; 11:00pm	*to Gradescope*
Part 3: Final Design Report	30%	Dec 8 2023; 5:00pm	*to Gradescope*
Part 4: Truss Testing	15%	Dec 9 2023; or by appt	*Room 113a, 110 Cummington Mall*

Memo from Washington Roebling, Chief Engineer of design and construction of the Brooklyn Bridge, to his assistant:

> There are so many points to be considered, so many conflicting interests to be reconciled on the parts of the truss that it is perfectly bewildering to pick out the best thing. For example, I want to reduce the aggregate weight so as to keep down the pressure on the masonry. I want to simplify the superstructure so as to make work in the shop easy and erection easy and safe, and I also want to keep down the wind surface as much as possible. On the other hand I want the truss sufficiently strong to resist a reasonable amount of bending, and this goes against the other points. But the only possible way in which I can reduce pressure on masonry and wind surface is by reducing the height and weight of the trusses and increasing the strain per square inch on the iron. I do not see that any reduction of weight is possible in any other parts of the structure. By making the truss rods of steel we make some reduction in weight but it is only in the low truss that the rod section is great enough to enable us to attain any appreciable advantage by the substitution of steel for iron. In the high truss with rods through two panels the section is hardly sufficient to make it worthwhile to change. This, therefore, would be one argument in favor again of reducing the weight of the intermediate truss and leaving the rods in all the trusses within one panel. This includes the two central trusses even if they are arranged with a square bar in the middle of two flat ones outside.

Source: McCullough, David G. The Great Bridge: The Epic Story of the Building of the Brooklyn Bridge. New York: Simon and Schuster, 1972. Print.

Contents

1 Overview

1.1 Goal and approach

The overall goal is to design a truss capable of supporting a given load from given materials. The design options are to be guided through engineering analysis. The key assumptions used in our analysis are:

1. The structure is well modeled as a pin-jointed two dimensional truss.
2. The strength of the truss members in tension is practically infinite.[1]
3. The strength of the joints is practically infinite[2]
4. The dominant failure mechanism is buckling of the individual members.

Based on these assumptions, you will create a computer program to predict the performance of candidate truss designs. The program will allow you to quantitatively evaluate the performance of a number of designs without going through the effort (in engineering terms, the expense) of building all of them.

The process leading to a successful design based on computational engineering analysis requires several steps:

- Step 1: *Characterize the materials.* Materials can vary from batch-to-batch. To quantify the buckling behavior and range of uncertainty in our chosen materials, a large selection needs to be measured. This is the purpose of the buckling lab.
- Step 2: *Model development & verification.* Create a computer program that uses assumptions 1-4 above to predict the performance of candidate truss designs and verify that it can correctly analyze a truss.
- Step 3: *Iterative Design.* Brainstorming multiple designs that adhere to a common set of specifications allows you to creatively tackle a common problem and evaluate the pros and cons of various approaches. Your computer program will allow you to quickly evaluate the relative performance of these designs and give us a chance to provide feedback.
- Step 4: *Final design.* Based off feedback on your design, verification of your analysis program, and general knowledge of the performance of your peers' designs, you will have the ability to iterate and optimize a final design. Try a bunch of variations!
- Step 5: *Truss testing.* The performance of your design (and those of all other groups) will be evaluated in a truss testing setting. Since each member of your team will build and test the same design you'll have the unique ability to explore variability in performance when real-world materials are used.

Each of these steps corresponds to a unique and specific part of the overall project design. This is organized to mimic the engineering design process that one might find in practice, e.g. in designing a new plane.

[1] The terminology "practically infinite" is used here in an engineering sense and not a mathematical sense. Nobody believes that the truss members can really sustain an infinite tensile force. Really what we mean is that other failure mechanisms become important long before fracture of the tension members.

[2] idem.

1.2 Specifications

The truss you design must conform to the following specifications.

1. **The truss must be a single, planar, simple truss. No truss member may be designed to extend below the line connecting the two end joints.**

   A simple truss starts with three members and three joints configured in a triangle. New triangles may be added by adding two new members with a single joint between them. Members may not cross each other or be doubled-up, and can only be joined to other members at their ends.

   Make sure your truss is a simple truss by checking first that it is comprised only of triangles. If any quadrilaterals are formed, your truss is incorrect! Second, the number of joints J and members M must be related[3] by

   $$M = 2J - 3.$$

2. **The truss must be designed to support a minimum live[4] load of 32** $oz.$**= 2** $lb.$ **The load must be placed on a joint located at a horizontal distance of 9-12** $in.$ **away from the pin support.**

   This implies that there must be a joint at that location along the bottom line. You are free to have any other number of joints along that line but you must have at least that one. Feel free to deviate from the classic 'train bridge' design where all the bottom-most joints are horizontal and in-line with each other (e.g. it doesn't have to *look* like the truss shown in Fig. 1, only be supported and loaded as shown).

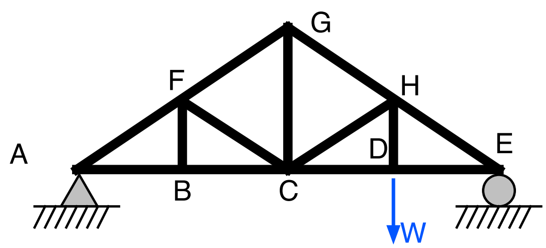

Figure 1: Simply supported two dimensional truss.

3. **The total (virtual) cost of the truss must be less than \$305** where the cost of the truss is defined as

$$\begin{aligned} \text{Cost} &= C_1\, J + C_2\, L && (1)\\ \text{where:} \quad C_1 &= \$10/\text{joint} && (2)\\ C_2 &= \$1/\ in., && (3) \end{aligned}$$

   with J = number of joints and L = total length of all members summed together.

Summary of distance and cost specifications

Joint-to-joint span L_{jj}	$8\ in. \leq L_{jj} \leq 16\ in.$
Truss span	33 $in.$
Load to pin support span	9-12 $in.$
Total virtual cost	< \$305

[3]Fun puzzle! Derive this!

[4]The "live load" is the load that is added to the structure. The structure's own weight is called the "dead load".

2 Model Verification and Preliminary Design

Building off the first part of the project, this second part has two goals.

- The first is to verify that your computational truss design analysis correctly predicts the internal forces in a truss design. This is called software or model "verification," as its purpose is to *verify* that your computer model is correctly solving the problem it is designed to solve.
- The second is to use the program to do an evaluation of (at least) two candidate truss designs that meet the specifications described in the Section above

The overall goal of the course project is to design the best truss you can that meets or exceeds the specifications laid out in Section 1.2. This effort implies that you will need to analyze your truss designs to determine their maximum failure load. You have learned (or will learn soon) how to do this in the course of the course. You will also have learned that figuring everything out for even a small truss is no small task, as determining the forces in each of the members with a known load and known support reactions leads to m coupled linear algebraic equations, where m is the number of members in the truss. The trusses you design will almost certainly have more than ten members leading to essentially a big pain in the brain – to say nothing of design optimization and the large possibility of human error if the calculations are done by hand.

Thankfully, they do not need to be done by hand. Instead, you will leverage your knowledge and experience in EK 125 to write a computational analysis code to do this for you. Matlab is recommended, but an alternative language, such as Python, is ok to use as well. Keep in mind you will be asked to submit a Matlab-formatted input file, as described below.

Why use Matlab? Matlab excels at solving systems of equations, particularly linear systems as in this scenario. The use of Matlab here will refresh your coding skills and is good practice for future courses and indeed your future career. Matlab can be downloaded to your personal computer by downloading the Matlab software package by visiting:
http://www.bu.edu/tech/services/cccs/desktop/distribution/mathsci/matlab/.
Matlab can also be found on the computers in the Ingalls Engineering Center.

When building any piece of software, it is essential that you verify its correctness. This is especially true in this project since your design results rely entirely on your code. Therefore, you will need to verify the results of your program against a problem you solve by hand. A small problem will be assigned on the main class website. You will need to solve this problem once by hand (on paper via a calculator), and then again using your computational analysis code. The results must, of course, agree. You will need to report both results in your Preliminary design report (see Section 2.3).

2.1 Program description

The purpose of the truss analysis is to determine the internal tensile force in each member and the support reaction forces. Here we assume that all applied loads are known and that the structure is a simple truss. Start off by numbering each of the J joints and each of the M members, in no particular order, along with the reaction forces S, as illustrated as an example in Fig. 2. where $S_{x,1}, S_{y,1}$ are the unknown pin support reactions at joint 1, $S_{y,2}$ is the unknown roller support reaction at joint 5, and W is an applied load (i.e., the weight on the relevant joint in your design).

There will be M+3 unknowns, M coming from the unknown forces in the members and three coming from the unknown reactions since there is one pin joint and one rocker joint. By doing

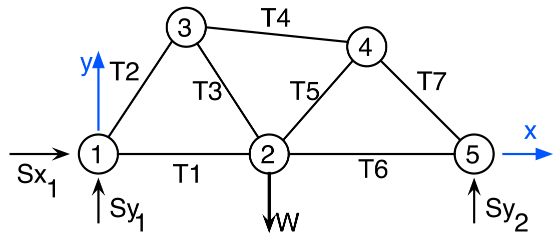

Figure 2: Illustration of joint and member numbering for an example of a 5-joint/7-member truss

an equilibrium analysis at all the joints (i.e. using sum of forces in x equals zero and sum of forces in y equal zero), we can obtain $2J$ equations. In order to solve for the member tensions in a simple truss, the number of equations should be equal to the number of unknowns. Of course, you are asked to build a simple truss in which the number of joints and the number of members is related by $M = 2J - 3$.

2.2 Algorithm

The following algorithm consists of two stages:

1. A definition of the truss parameters: the joint locations, the member-joint connections, the reaction forces locations, and the load magnitude.
2. A construction of the system of equilibrium equations and solution for the unknown forces.

2.2.1 Defining the truss parameters

First we define a *connection matrix* **C**. This matrix has j rows and m columns, where the row represents the joint number and the column represents the member number (thus, the first column corresponds to member 1 and the first row corresponds to joint 1). We indicate the connection of member 1 to joints 1 and 2 by placing a '1' in column 1 of rows 1 and 2. If a given joint is not connected to a given member, we place a '0' in the matrix location that corresponds to the joint and member numbers. This can be summarized as:

$$\mathbf{C}_{j,m} = \begin{cases} 1, & \text{if member } m \text{ is connected to joint } j \\ 0, & \text{elsewhere} \end{cases}$$

The end result should work out such that the sum of each *column* is 2, since each member is only connected to two joints. The sum of each row should equal the number of members attached to the corresponding joint. For the arrangement shown in Fig. 2, we would have the following connection matrix:

$$\mathbf{C} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}.$$

Next we construct a connection matrix for the support forces along each axis, where $\mathbf{S_x}$ and $\mathbf{S_y}$ are matrices with j rows and 3 columns. Note that for our statically-determinate truss, supported by one pin and one roller joint, we will have a total of three unknown reactions. In each matrix, for each unknown reaction force, put a '1' in the column that corresponds to the joint j (there should be only a single entry of '1'; note that this is true in both matrices even though we know that for the loading conditions in this project, there are no support forces in the x direction) (and, another parenthetical note: be sure you understand and agree with the previous parenthetical remark!). For the example in Fig. 2 (where a pin and roller support is modeled), we get

$$\mathbf{S_x} = \begin{array}{c} \begin{matrix} S_{x1} & S_{y1} & S_{y2} \end{matrix} \\ \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \end{array}, \qquad \mathbf{S_y} = \begin{array}{c} \begin{matrix} S_{x1} & S_{y1} & S_{y2} \end{matrix} \\ \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \end{array}$$

The truss is also defined by the location of the joints; to capture these we construct two location vectors $\mathbf{X}$ and $\mathbf{Y}$. Each has j elements corresponding to the relevant location of the jth joint; that is

$$\mathbf{X} = [x_1, x_2, x_3, x_4, ...], \;\; \mathbf{Y} = [y_1, y_2, y_3, y_4, ...];$$

Choose your reference frame carefully and then locate the position for the joints accordingly.

Finally, we define the load vector $\mathbf{L}$ which represents the known forces that act on each joint. This vector has $2j$ elements; the first j elements correspond to loads in the x direction for each of the j joints, and the last j elements represent loads along the y direction. In our example in Fig. 2, the vertical force $\mathbf{W} = -mg\hat{\boldsymbol{\jmath}}$ for the load is placed on joint 2. In a standard force equilibrium equation, the force $\mathbf{W} = -mg\hat{\boldsymbol{\jmath}}$ would be combined with the other vertical forces to equal zero. Once this known force is moved into the $\mathbf{L}$ matrix (see Eqn. 5 below), its sign is flipped and becomes positive. Therefore

$$\mathbf{L} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ +mg \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{array}{l} \text{no horizontal load at J1} \\ \text{no horizontal load at J2} \\ ... \\ ... \\ ... \\ \text{no vertical load at J1} \\ \text{load } mg \text{ at J2} \\ \text{no vertical load at J3} \\ ... \\ ... \end{array} \tag{4}$$

2.2.2 Constructing the equilibrium equations

We would like to construct the equilibrium equations using only the matrices and vectors described above. We can achieve this by using the method of joints of determine the forces at each joint j. To describe the method, we start with joint 1 in Fig. 2. Its FBD is detailed in Fig. 3.

Summing the forces in the x–direction, we get

$$\begin{aligned} \sum F_{x,1} \quad : \quad & \left(\frac{x_2 - x_1}{r_{1,2}}\right) T_1 + \left(\frac{x_3 - x_1}{r_{1,3}}\right) T_2 + 0 \cdot T_3 + 0 \cdot T_4 \\ & +0 \cdot T_5 + 0 \cdot T_6 + 0 \cdot T_7 + 1 \cdot S_{x,1} + 0 \cdot S_{y,1} + 0 \cdot S_{y,2} = 0 \end{aligned}$$

where $r_{1,2}$ is the distance between joint 1 and 2 and the overall fraction is the x-axis unit vector for that force. We note that here we use the symbol T_m to denote the internal *signed tension* in

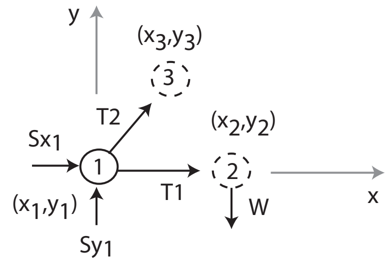

Figure 3: Illustration of the method of joints at joint 1.

member m. By *signed tension* we mean that if T_m is positive, then the member is in tension; if T_m is negative, then the member is in compression.The rest of the joints would be considered by working out the equilibrium equations along the x axis, resulting in a total of j equations along the x–axis. For the arrangement in Fig. 2, the second equation would represent $\sum F_x$ for joint 2, and so on. After considering the x–axis, we move on to the y–axis. The sum of the y–forces at the first joint is given by

$$\begin{aligned}\sum F_{y,1} \quad : \quad & \left(\frac{y_2 - y_1}{r_{1,2}}\right) T_1 + \left(\frac{y_3 - y_1}{r_{1,3}}\right) T_2 + 0 \cdot T_3 + 0 \cdot T_4 \\ & + 0 \cdot T_5 + 0 \cdot T_6 + 0 \cdot T_7 + 0 \cdot S_{x,1} + 1 \cdot S_{y,1} + 0 \cdot S_{y,2} = 0\end{aligned}$$

Note that this is written in a general form given the position of the joints. For example, the first term in the equation $(y_2 - y_1)$ is clearly zero since those two joints are on the same horizontal line.

The goal now is to use linear algebra to solve of the unknown forces by separating the system of linear force equations into three matrices, $\mathbf{A}$, $\mathbf{L}$, and $\mathbf{T}$ where

$$[\mathbf{A}]\,[\mathbf{T}] = [\mathbf{L}] \tag{5}$$

and $\mathbf{A}$ is a matrix that should be populated by the coefficients of the force for the respective member tension at each joint, starting with the forces along the x axis for rows 1 to j, and finishing with the forces along the y axis for rows $j + 1$ to $2j$. It should be $2j$ rows and m+3 columns, where the last three columns are the $\mathbf{S}_x$ and $\mathbf{S}_y$ matrices. That is,

$$\mathbf{A} \; = \; \begin{array}{l} \begin{array}{|ccccccc|c|} m_1 & m_2 & m_3 & m_4 & m_5 & m_6 & m_7 & \quad\mathbf{S}\quad \end{array} \\ \begin{bmatrix} \frac{x_2-x_1}{r_{1,2}} & \frac{x_3-x_1}{r_{1,3}} & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ \frac{x_1-x_2}{r_{1,2}} & 0 & \frac{x_3-x_2}{r_{2,3}} & 0 & \frac{x_4-x_2}{r_{2,4}} & \frac{x_5-x_2}{r_{2,5}} & 0 & 0 & 0 & 0 \\ 0 & \frac{x_1-x_3}{r_{1,3}} & \frac{x_2-x_3}{r_{2,3}} & \frac{x_4-x_3}{r_{3,4}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{x_3-x_4}{r_{3,4}} & \frac{x_2-x_4}{r_{2,4}} & 0 & \frac{x_5-x_4}{r_{5,4}} & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & & \\ - & - & - & - & - & - & - & - & - & - \\ \frac{y_2-y_1}{r_{1,2}} & \frac{y_3-y_1}{r_{1,3}} & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ \frac{y_1-y_2}{r_{1,2}} & 0 & \frac{y_3-y_2}{r_{2,3}} & 0 & \frac{y_4-y_2}{r_{2,4}} & \frac{y_5-y_2}{r_{2,5}} & 0 & 0 & 0 & 0 \\ 0 & \frac{y_1-y_3}{r_{1,3}} & \frac{y_2-y_3}{r_{2,3}} & \frac{y_4-y_3}{r_{3,4}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{y_3-y_4}{r_{3,4}} & \frac{y_2-y_4}{r_{2,4}} & 0 & \frac{y_5-y_4}{r_{5,4}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{y_2-y_5}{r_{2,5}} & \frac{y_4-y_5}{r_{5,4}} & 0 & 0 & 1 \end{bmatrix} \end{array} \begin{array}{l} \text{x components} \\ - \\ \text{y components} \end{array}$$

The unknown forces, $\mathbf{T}$, are defined in a matrix consisting of one column and m+3 rows:

$$\mathbf{T} = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \\ T_7 \\ S_{x,1} \\ S_{y,1} \\ S_{y,2} \end{bmatrix}$$

The $\mathbf{L}$ matrix was defined above. Since we are interested in solving for the unknown forces in $\mathbf{T}$, but know the values that populate $\mathbf{A}$ and $\mathbf{L}$, we can invert Eq. 5 to solve for $\mathbf{T}$ to get

$$\mathbf{T} = \mathbf{A}^{-1}(\mathbf{L}). \tag{6}$$

Important note: Even if there is no loading on the truss along the x-axis, as will be the case for your truss load, you must make sure to still represent the $S_{x,1}$ constraint in the matrix calculation. Failure to do so will prevent your matrix from being invertible.

2.2.3 Maximum theoretical load

One aspect of the analysis that you'll have to grapple with is how to accurately determine the failure load of your designs. One method could be to ramp up the test load until one of the members is at its maximum load (as determined by the buckling strength and the member lengths). Adjusting that load up by hand is an inefficient and inaccurate way to find that max load – that's just the concept behind it.

2.2.4 Accounting for the live load

The "live load" is the extra load that our structure might carry besides its own weight. For a train bridge, for example, the weight of the bridge is the "dead load". The weight of a train is the "live load". Once the structure is designed and built, the dead load does not change. The live load can change from moment to moment over the life of the structure. This concept applies to real-world trusses where the member weight is a consideration. Given the relatively low value for the member weight compared to the applied load and the overall uncertainty for the buckling strength fit, we will approximate the effect of the dead load as small and neglect it for this project.

Live load: You will want to easily compute the internal tensions due to a number of different live loads, in order to find the live load that causes structural failure. You can do that easily and efficiently using the concept of *linearity*.

Let ℓ be the number of the loaded-joint where you wish the "live" load to be applied. Let W_ℓ be the magnitude of the live load applied to joint ℓ. Let T_m represent the tension in member m due to the live load W_ℓ. The principle of linearity states that the internal tensions due to W_ℓ are proportional to W_ℓ. That is,

$$T_m = R_m \times W_\ell. \tag{7}$$

The value of R_m is independent of W_ℓ. Therefore, if you compute R_m from one run of your code with one value of W_ℓ, you can find T_m for *any* value of W_ℓ using equation (7).

Critical member and maximum load: Note that the force required for a particular member to buckle, P_{crit} is based off the member geometry and material properties (further note that it will have a negative value). P_{crit} itself is independent of the parameters in Eq. 7, but we can use its value to solve for the maximum theoretical load $W_{failure}$. The critical member c will buckle when

$$\begin{aligned} T_c &= -P_{crit,c} && (8) \\ &= W_{failure} \times R_c. && (9) \end{aligned}$$

Solving for $W_{failure}$ gives

$$W_{failure} = \frac{-P_{crit,c}}{R_c} \qquad (10)$$

While it's possible to design a truss such that multiple members experience $T_m = -P_{crit,m}$, it's more likely than not that only one member will be the critical member. To find the critical member(s), one can evaluate Eq. 10 for each member; the minimum such value will correspond to the critical member.

2.2.5 Verification of computational analysis

The most efficient way to analyze (and optimize) multiple designs is to write a central analysis code and set it up to accept an input file that contains the details for the truss design (e.g., the C, Sx, Sy, X, Y, and L matrix values) and output the results to the command line or a separate file. Additionally, it's in your best interest to know whether your code is valid: the basis of your eventual test results depend on this code.

We'll rely on an internal and external verification method:

Internal: You will verify your results by using your code to solve a standard truss problem and compare your results to your manual solution of this truss. The problem is posted on the project folder on the course website.

External: The GSTs will analyze your design performance with our central code. The GSTs will verify whether your results are correct, and will provide feedback on your preliminary report to alert you of any mistakes. In order to do this efficiently, it is a requirement that you submit the details for one of your preliminary truss designs, with these details described in a Matlab input file.

Input file With all this in mind, set up a general analysis code that will accept an input file with the following input parameters and their values:

1. The connection matrix **C**; (i.e.: C = [1 1 0 0 ... 0; 1 0 0 0 ... 0; ...];)
2. The S_x matrix of reaction forces in the x-direction;
3. The S_y matrix of reaction forces in the y-direction;
4. The joint location vectors X and Y;
5. The vector of applied external loads **L**.

Save these parameters to a .mat file, using the following syntax in Matlab:

```
save('TrussDesign1_MaryJoeBob_A1.mat','C','Sx','Sy','X','Y','L')
```

NOTE: Your input file MUST be in the .mat format (NOT PDF, Word, .dat, .txt, etc!). Failure to format this correctly will result in a loss of points due to the difficulty in checking your file to give you the necessary feedback. See your instructor or any of the GSTs or LAs for assistance if necessary.

Output format The output from your code should display your group member names and course section identifier, along with the applied load, truss cost, and load/cost ratio for the truss. Your code should print out the identifier for each member, and the magnitude of the member's load with a (T) if in tension or a (C) if the member is in compression. It should also list the label for the reaction force, followed its value. For example, if the load you apply is 30 oz., and the members have been designated as m1, m2, ... m15, the output should appear as:

```
\% EK301, Section A1, Group 1: Washington R., Emily R., 2/15/20xx.
Load: 30 oz
Member forces in oz
m1: 0.991 (C)
m2: 0.273 (T)
. . .
m15: 0.827 (T)
Reaction forces in oz:
Sx1: 0.0
Sy1: 0.75
Sy2: 0.25
Cost of truss: $319
Theoretical max load/cost ratio in oz/$: 0.0031
```

2.2.6 Matlab design file

Your section should have a Gradescope assignment entitled "Truss design file"; you should upload your Matlab .mat input file for your **first** truss design (one per group) by the preliminary report deadline so that your program and its output can be verified using our analysis code. You only need to upload one file per group, for the **preliminary report**, not the final report. You only need to upload your design file; you do *not* need to upload your analysis file. Your full report should be submitted to Gradescope via the "Preliminary Design Report" assignment link.

2.3 Preliminary Design Analysis

The design stage of this project specifies a set of somewhat conflicting requirements for the truss. To have a high strength to weight ratio, we desire a strong inexpensive truss, but stronger trusses tend to be more expensive. Your computer program will allow you to explore a variety of truss designs to find a good balance between strength and cost. The primary goal of the preliminary design phase is to explore (at least) two different options to get a sense of how the different design decisions affect the results.

In your analysis of each design, you should provide the following:

1. **Prediction of the force in each member for a given vertical load given at the specified load joint.**

   This prediction should be computed using your analysis program. It should include not only the magnitude of the force in each member but also whether that member is in tension or compression.

2. **Determination of the member to buckle first.**

   This should be calculated based on the class average best-fit relationship between buckling load and member length. Report the member, its length, its predicted buckling strength, and the uncertainty in that strength.

3. **Specification of the maximum load that the physical truss could support.**

   Report the maximum load and the uncertainty in that load. To calculate this last item, use the uncertainty in the strength of the member that will buckle first.

4. **Calculation of cost and load-to-cost ratio.**

   The cost of the truss should be calculated based on the total length of the members. Please note that you are not actually paying any money; this is an artificial cost from an artificial formula. The formula (Eq. (1), in the Specifications section), however, captures some real engineering considerations. For example, the number of joints is weighted heavily, partly because joints are expensive to fabricate but also because it is a reflection of the number of shorter members that must be used. The formula also depends on the total length; this of course represents the total amount of material needed.

   The load-to-cost ratio is exactly that: the ratio of the maximum load to the truss cost.

It is strongly suggested that you develop an automated means for calculating the member to fail, the cost, and load-to-cost values using Matlab, Excel, or similar. This will allow you to easily compare different designs. To encourage design optimization, the load and load-to-cost ratio will be graded relative to the performance of the final design for each group in your section.

2.4 Assignment: Model Verification and Preliminary Design Report Sections

Due *to Gradescope* on Nov 17 2023; 11:00pm.

The goal of this report is to describe your model verification and to discuss your two preliminary designs. General guidelines on report writing are described Appendix A. For this report, please address the specific elements described below.

- **Introduction**

  Describe the motivation for using a computer program to analyze a truss, and how you plan on using the program to evaluate candidate truss designs.

- **Method & Analysis**

  1. Describe your computational approach and verify it via your analysis of the standard truss problem assigned on the website. Solve this problem:
     (a) by hand (A handwritten solution is OK so long as it is neatly presented.)
     (b) by your computer code. Include a print-out of the code output and final result.

     The results from the two methods must agree. Resolve any discrepancies before submitting your report.
  2. Respond to the four items described above in Sec. 2.3.

- **Results**

  1. Include a diagram of each design with all members and joints clearly labeled in a fashion consistent with the output of your software. Highlight the member that will buckle first. It also includes the output of the code with the load in each member. This is probably best reported using a table that includes, for each member:
     (a) Member number (consistent with the design drawing)
     (b) Member length
     (c) Whether in tension or compression
     (d) Buckling strength and its uncertainty, based on the length (where the latter should be based on the uncertainty of the class average buckling strength fit). These parameters should only be stated for members that are in compression.
     (e) Magnitude of the force at (nominal) maximum truss load
  2. Include the critical member, its length and buckling strength and uncertainty, the maximum theoretical load and uncertainty, truss cost, and load-to-cost ratio for each design.

- **Discussion & Conclusion**

  Discuss your results, comparing the two designs. Support your conclusions about which is the better design and why as well as how you might further improve your designs.

Separately, make sure to:

- As a group: submit the Matlab input file that corresponds to your first truss design *to Gradescope*.

- Individually: complete the PDR peer assessment form (Google form: `https://forms.gle/Jnd9eSqjUhb8JD1V8`).

A Guidelines on writing reports

For all reports, proper format and proper English usage are required. All reports must be clear and user friendly. Each deliverable should be interpreted as one per design group. Be sure to include your section number on the title page, along with your team and member names. All of your reports for this course must be at least two pages long, though you should find that they will be longer than that.

General guidelines to follow include the following.

1. Include all experimental data you collect.
2. Show all equations used and define all variables.
3. Typeset your document for maximum readability. The only exceptions are handwritten meeting notes or hand-drawn schematics.
4. Be consistent with your variable names.
5. Number your plots, figures, and equations throughout the text.
6. Cite all references
7. Proofread for typos, spelling, grammar, formatting, and general writing flow. This is especially important when multiple authors are involved.

A comprehensive report should include the following:

1. Cover page

   This should contain the title of the report, the name of the group, the names of the members of the group, the section, and the name of the professor of the section.

2. Introduction

   This explains the purpose of the report/lab/testing that was done. Discuss what you intended to learn from the experiment/test/analysis/design and how you plan on using what you have learned.

3. Procedure (if applicable)

   This describes what you did to gather your data. You should describe any experimental apparatus in detail.

4. Data

   Present the data in tabular form. Do not forget to include units! Be sure to include a brief description that orients the reader to the source of the data.

5. Analysis

   Describe the analysis that you performed on the data. Show all equations with all symbols defined. Show an example for each unique calculation (e.g. sum of moments, standard deviation, mean buckling load, etc.). Refer to any figures (such as FBDs), data tables, or tabular presentations of your results as needed.

6. Results

   Present the results of your analyses in tabular and/or graphical form in a way that is easy for the reader to follow and interpret. Label and reference each table and graph.

7. Discussion & Conclusion

   Answer any questions that you have been asked to answer in the lab/project manual. Discuss your results. Do they make physical sense? Do they help you accomplish the goals you set out in your introduction? Discuss the uncertainty in your data and the sources of error. What did you learn? How will the results be used? What might you suggest doing differently next time?

8. Appendices

   Attach any hand calculations, computational code, extra data tables, alternative designs you considered but didn't use, and other relevant information that are important but did not make their way into the main report. Be sure to reference your appendices at some relevant point in your report. (Notice, for example, that this appendix was referenced earlier in this document.)

B Rubrics

B.1 Buckling Lab Rubric

Buckling Report Rubric	
Report Section	**Points**
Title Page	2
Background	2
Methods	5
Analysis	15
Results: Data table	15
Results: Plot	15
Discussion	20
Conclusion	5
Appendix	10
Quality of Writing and Presentation	11
Total	100

B.2 Preliminary Design Report Rubric

Preliminary Design Report Rubric	
Report Section	**Points**
Title Page	2
Introduction	5
Theory	5
Data and Design	
Designs: Diagrams	6
Designs: Cost and specifications	12
Analysis	
Input file: submitted & correct	5
Model verification	11
Designs: Max load calculation	18
Results	7
Discussion	20
Quality of Writing and Presentation	9
Total	100

B.3 Final Design Report Rubric

Final Design Report Rubric	
Report Section	**Points**
Title Page	2
Introduction	5
Procedure	5
Analysis	5
Results	
Final design diagram	7
Final design table	20
Summary	10
Discussion	20
Appendix	10
Quality of Writing and Presentation	16
Total	100